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Kato et al.

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(54) **FULL-DUPLEX OPTICAL TRANSCEIVER APPLICABLE TO DIGITAL COHERENT SYSTEM**

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H04B 10/61 (2013.01)
G02B 6/42 (2006.01)

(52) **U.S. Cl.**

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(58) **Field of Classification Search**

CPC H04B 10/611
See application file for complete search history.

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(57) **ABSTRACT**

An optical transceiver applicable to the coherent communication is disclosed. The optical transceiver includes a laser module, a transmitter module to output a transmitting signal by modulating a phase of an laser beam output from the laser module, and a receiver module to receive a receiving signal modulated in the phase thereof and extract data by multiplying the receiving signal with an laser beam output from the laser module.

11 Claims, 19 Drawing Sheets

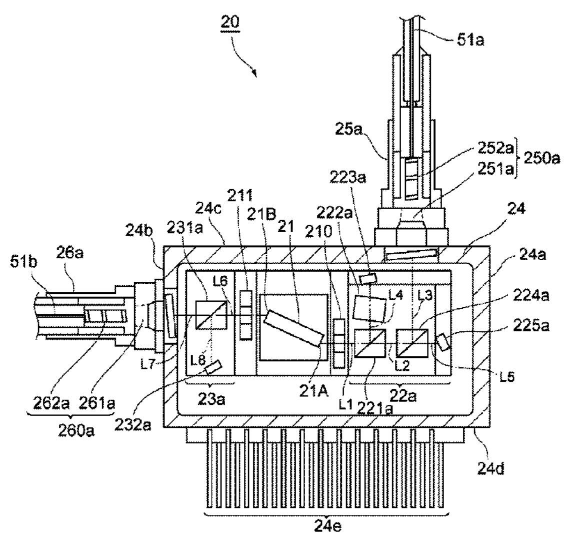
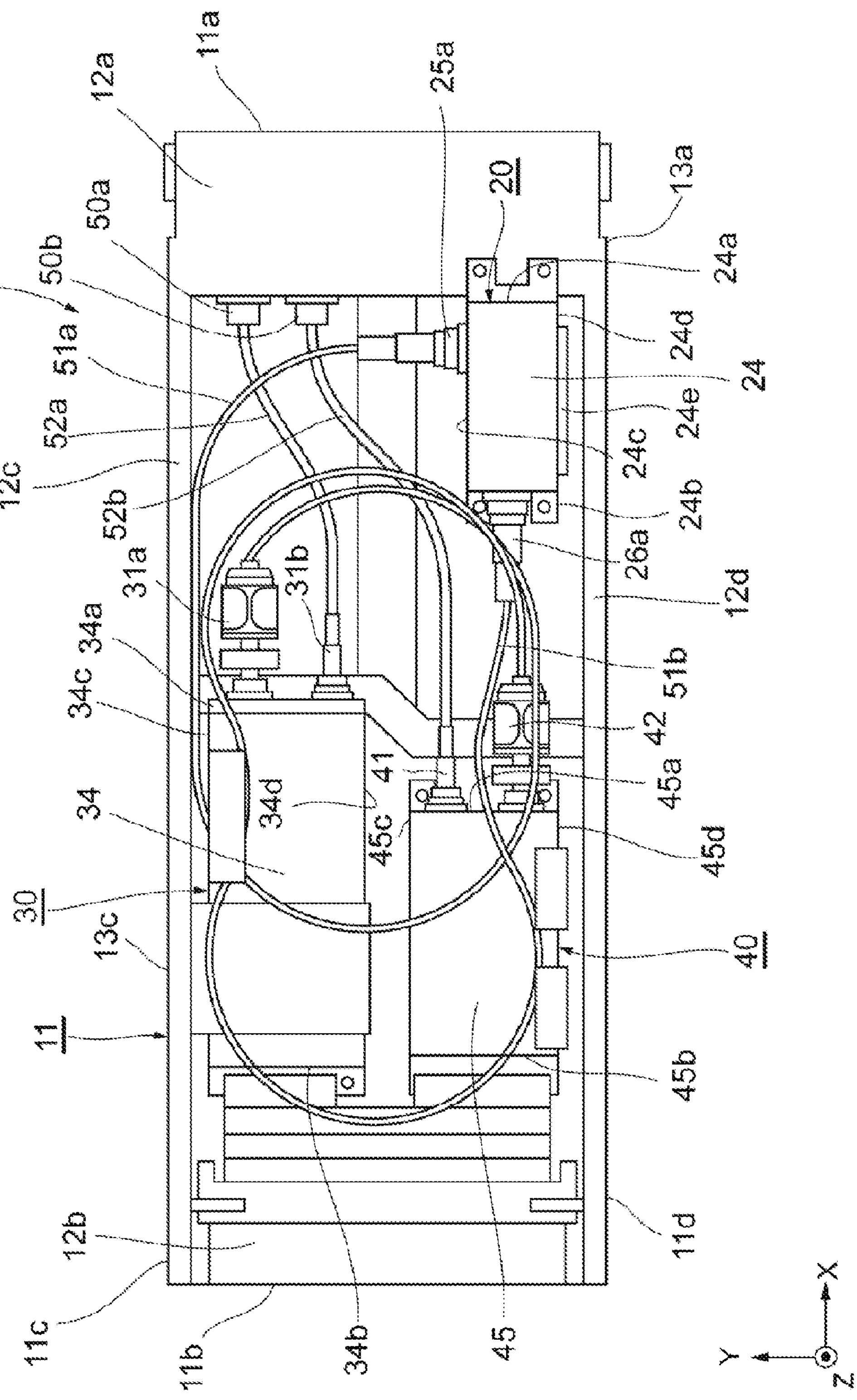


Fig.1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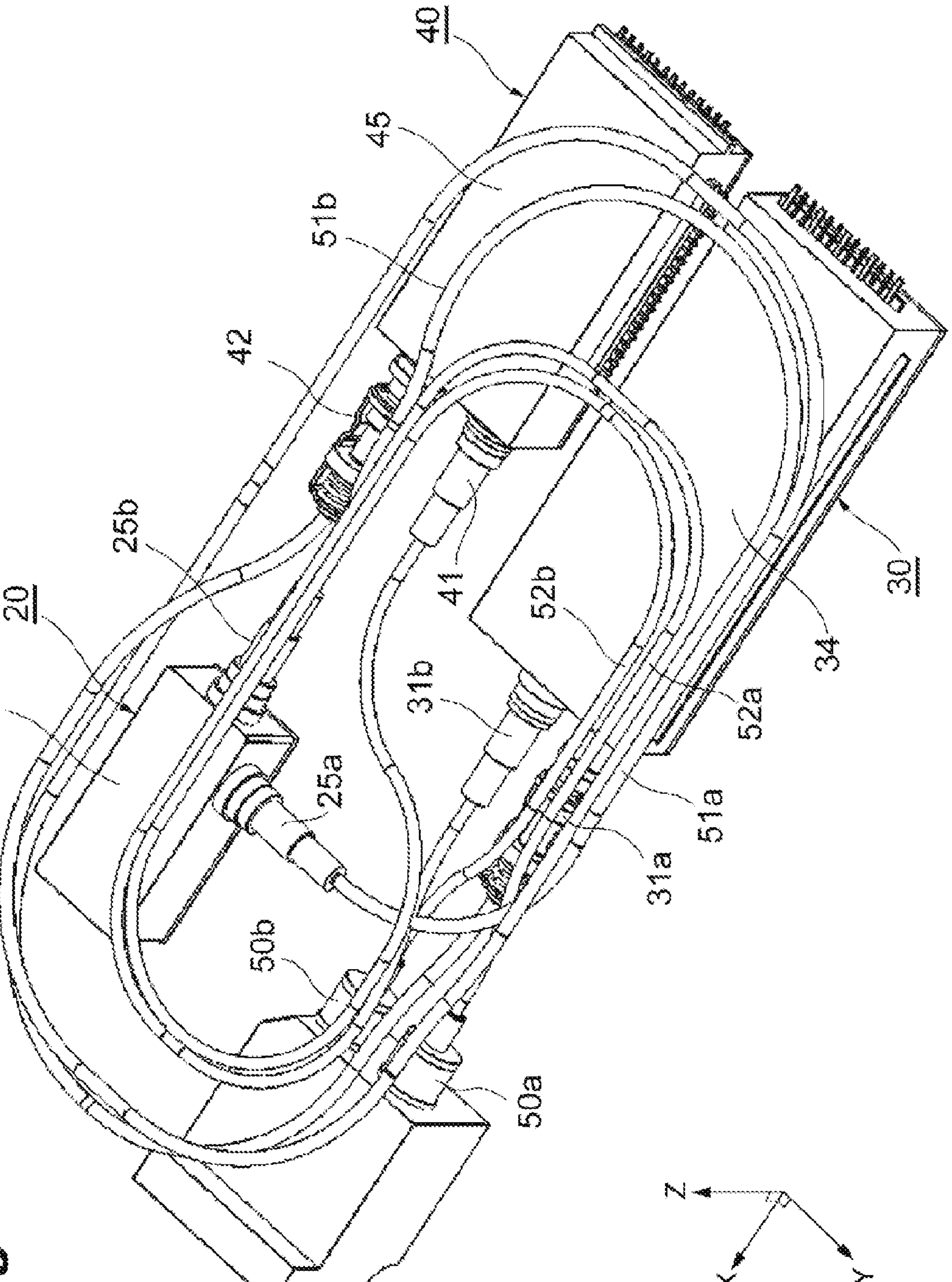
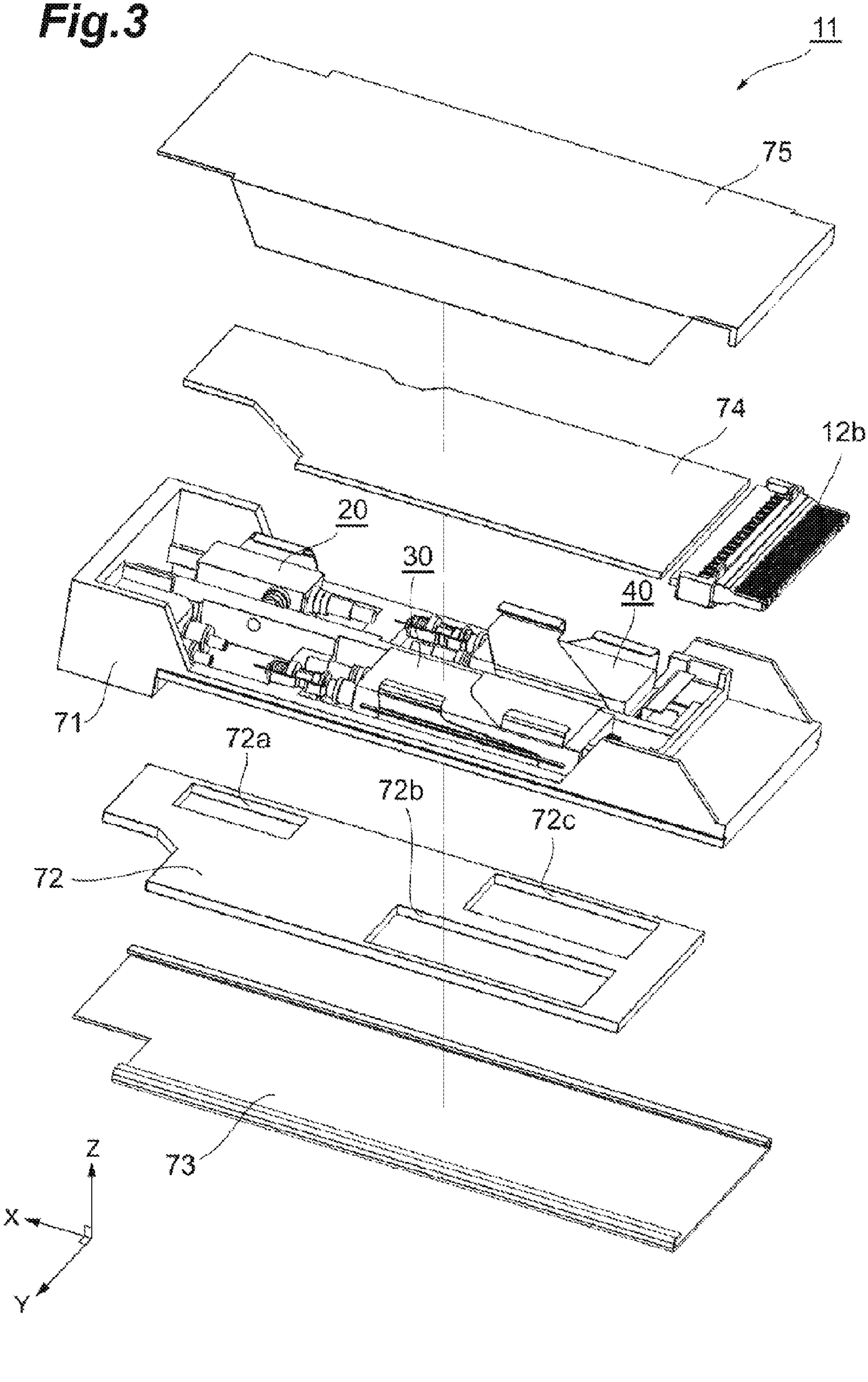


Fig.2

Fig.3



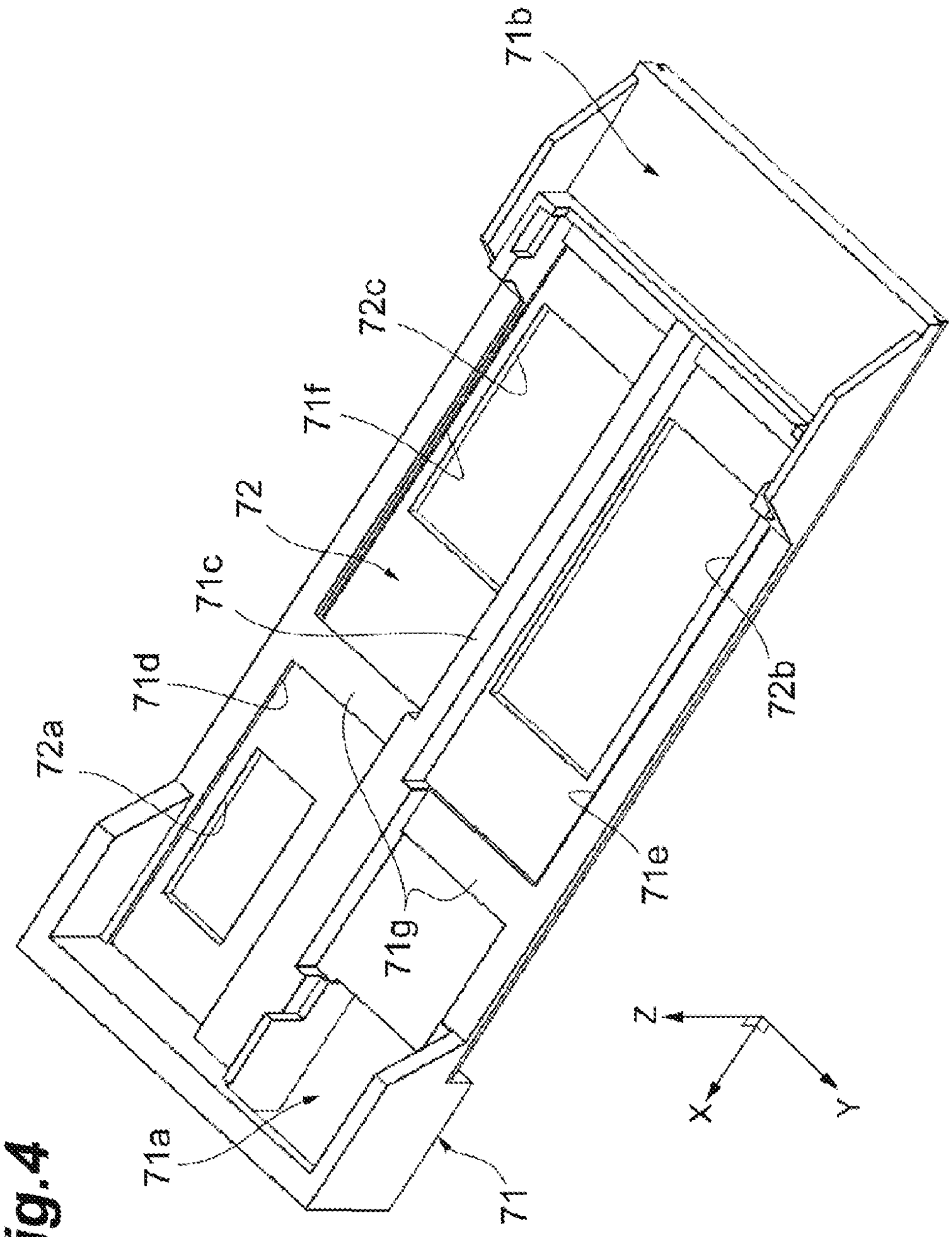
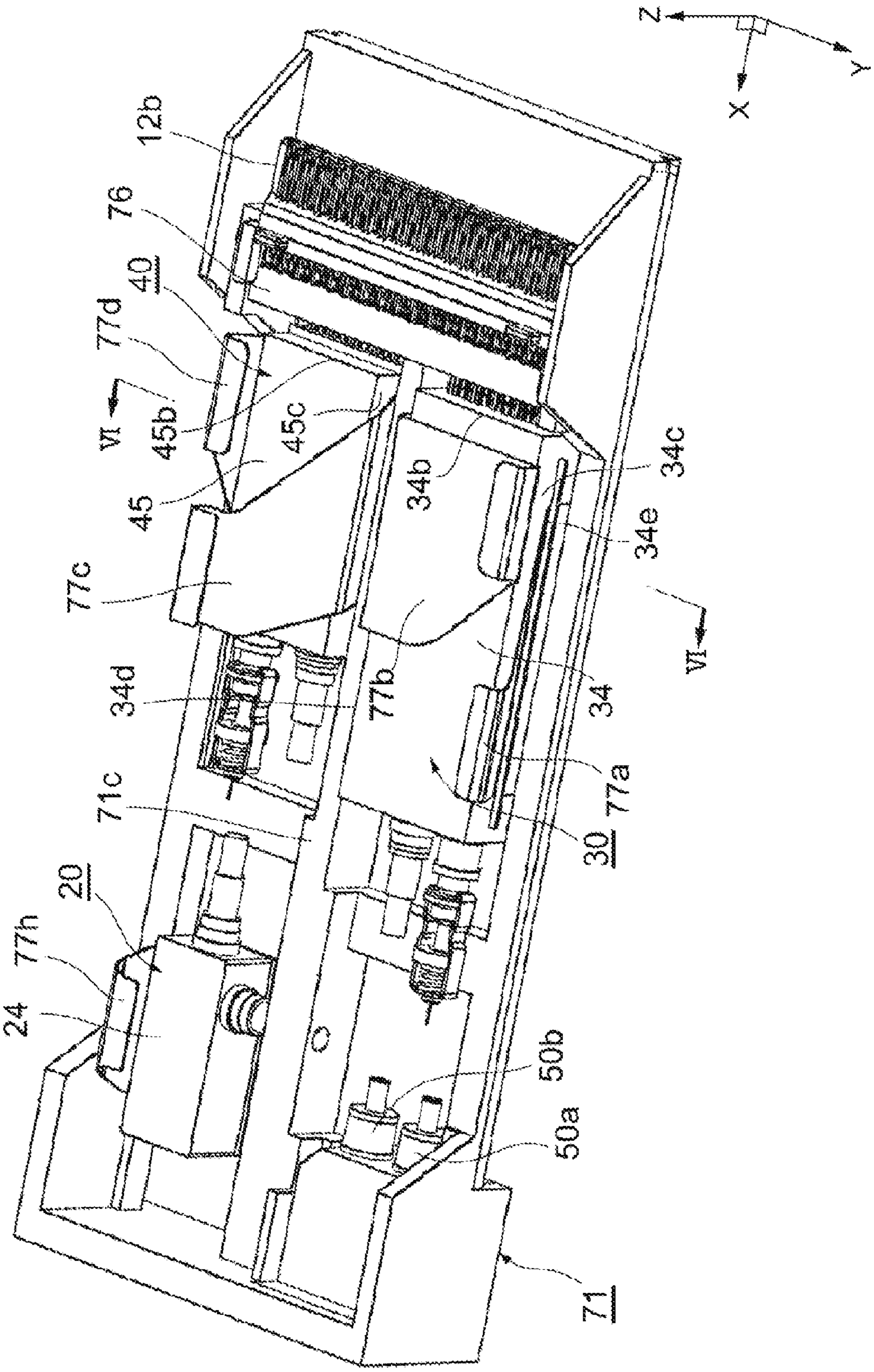


Fig.4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77h
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50b
50a
71

Fig.5

Fig.6

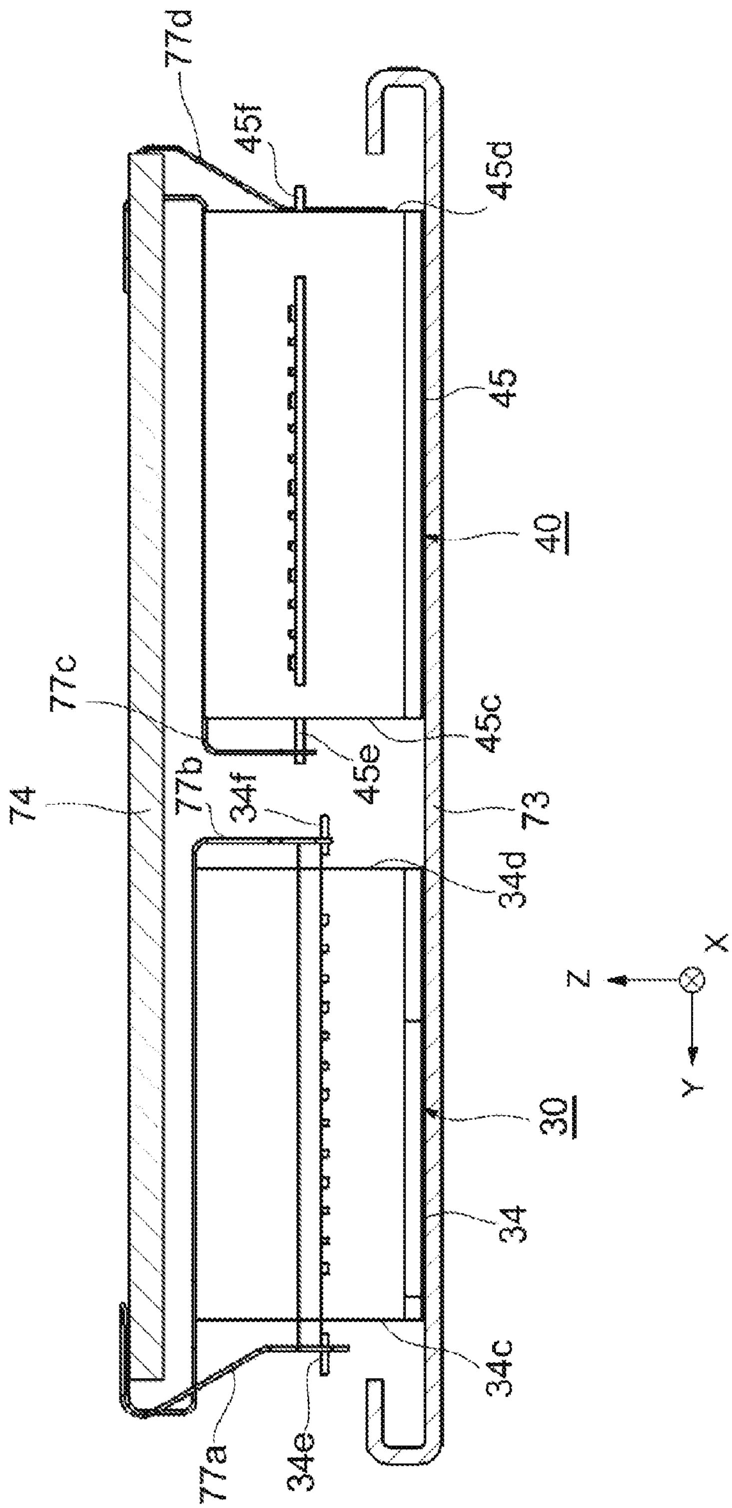
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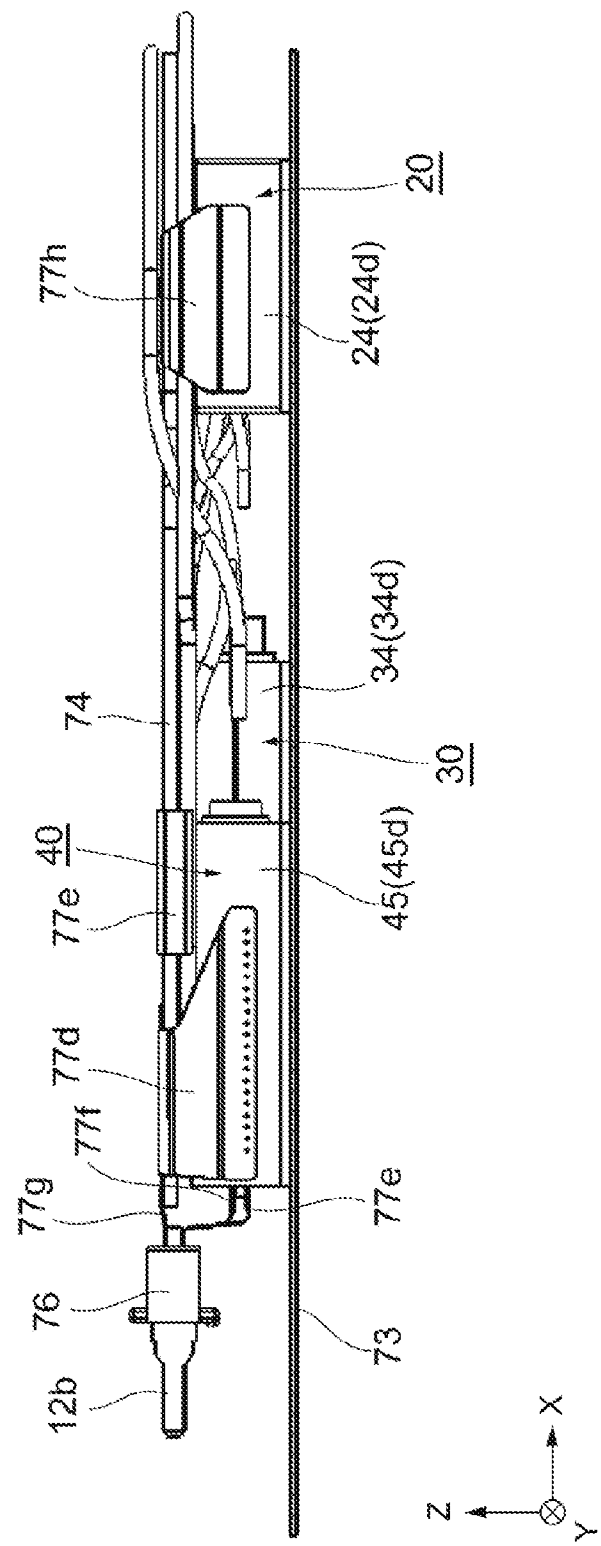
Fig.7



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34(34d)
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45(45d)
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73
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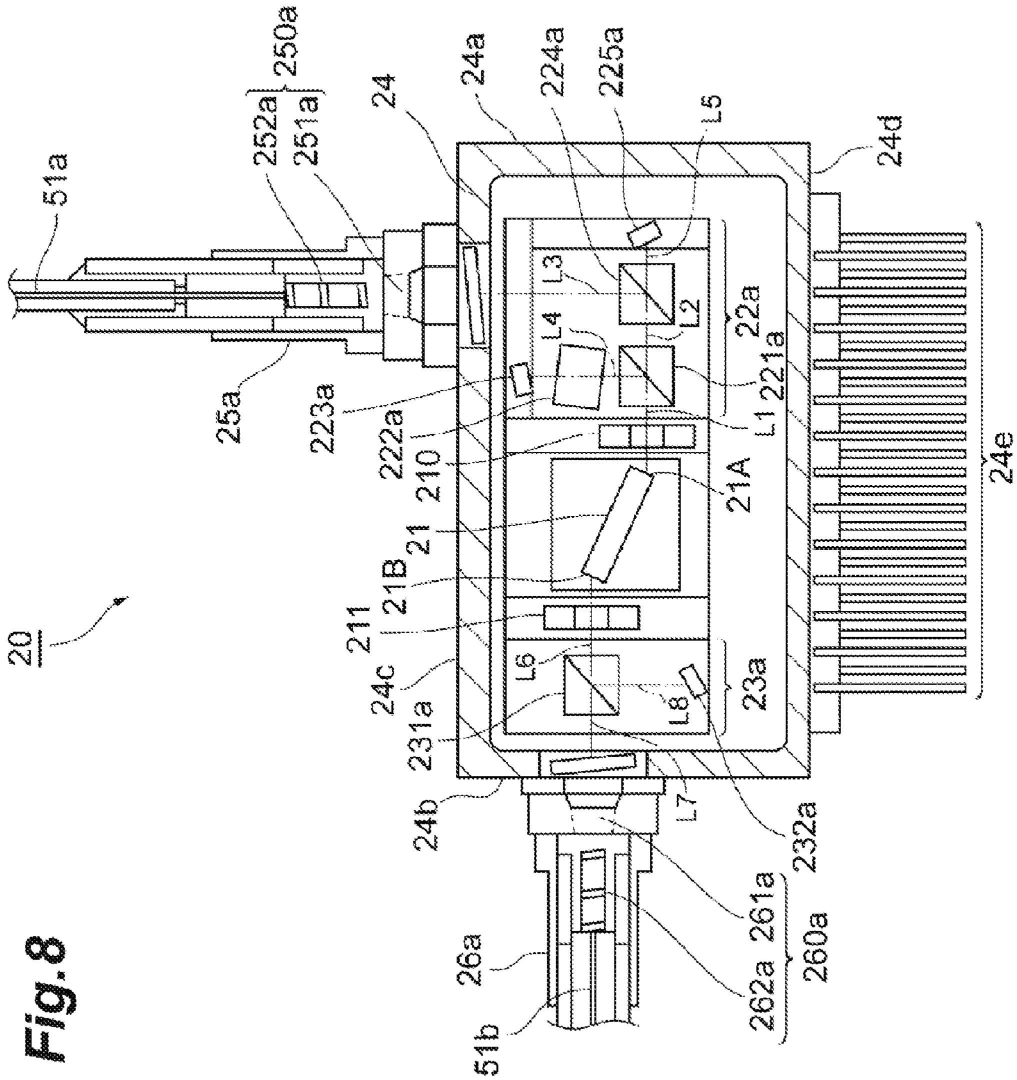
Z
Y

Fig.8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222a
L1
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21A
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21B
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26a
51b
24d
24e

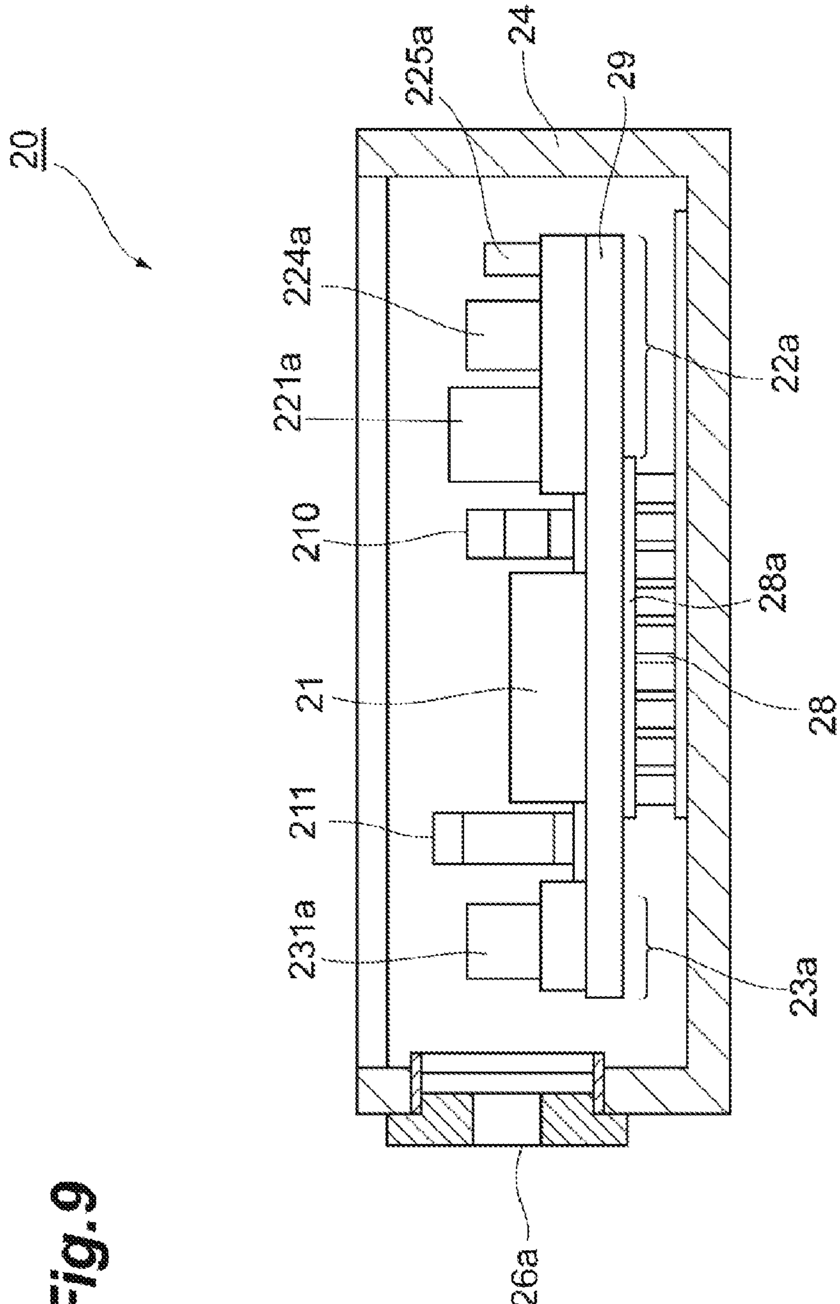
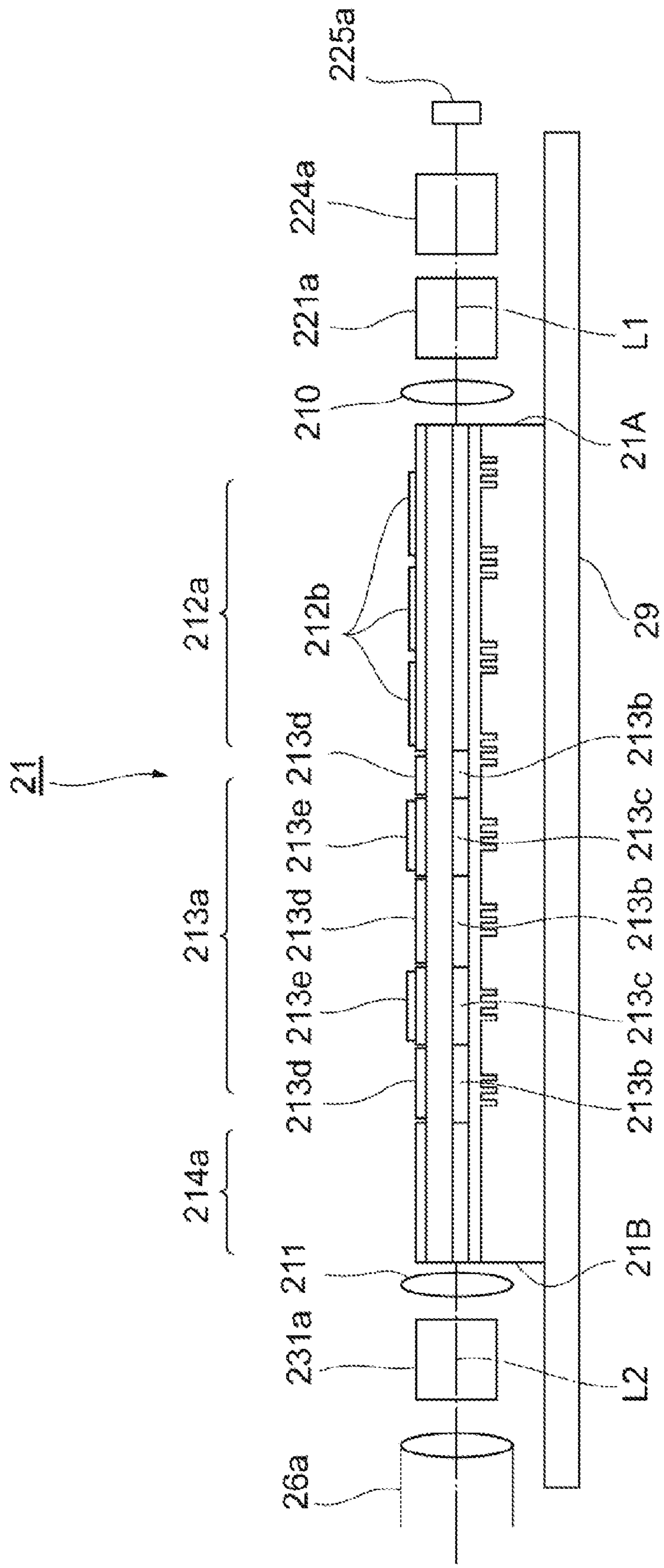


Fig.9

Fig. 10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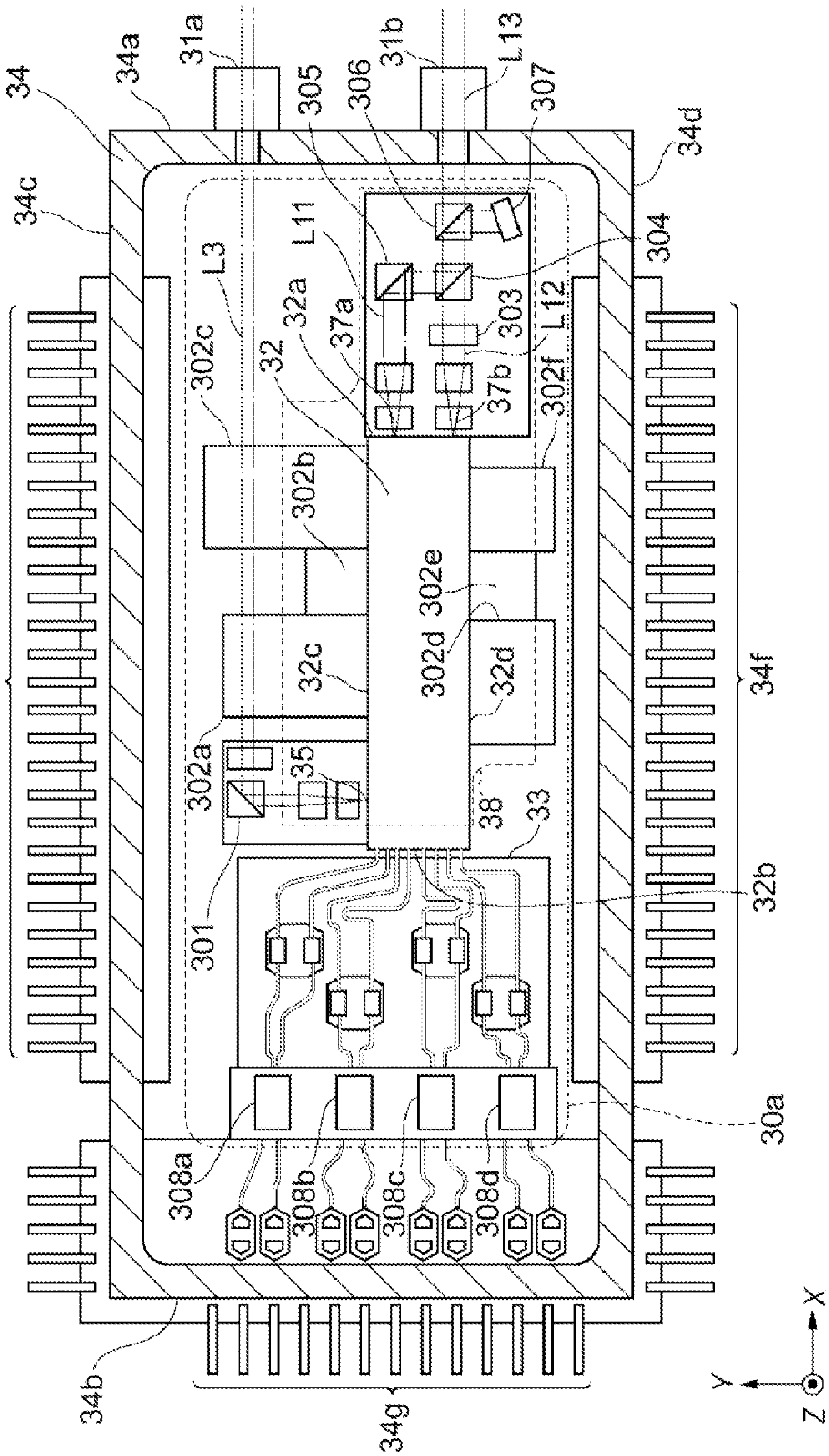
21B
231a
L2
26a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307
308a
308b
308c
308d
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32b
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32d
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35
37a
37b
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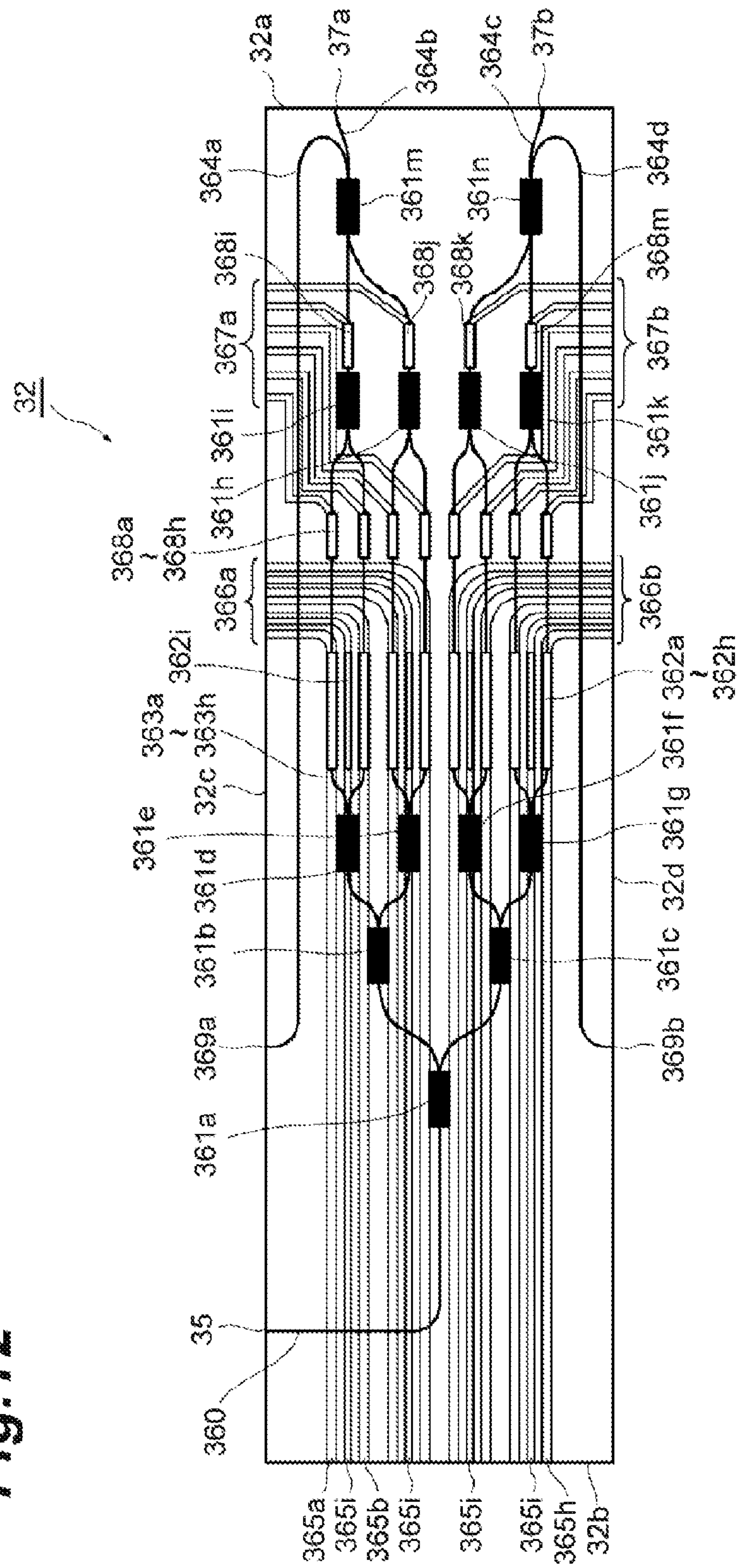
X
Y
Z

Fig.11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368k
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361j
368a
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368h
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362i
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363a
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32c
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361g
361d
32d
361b
361c
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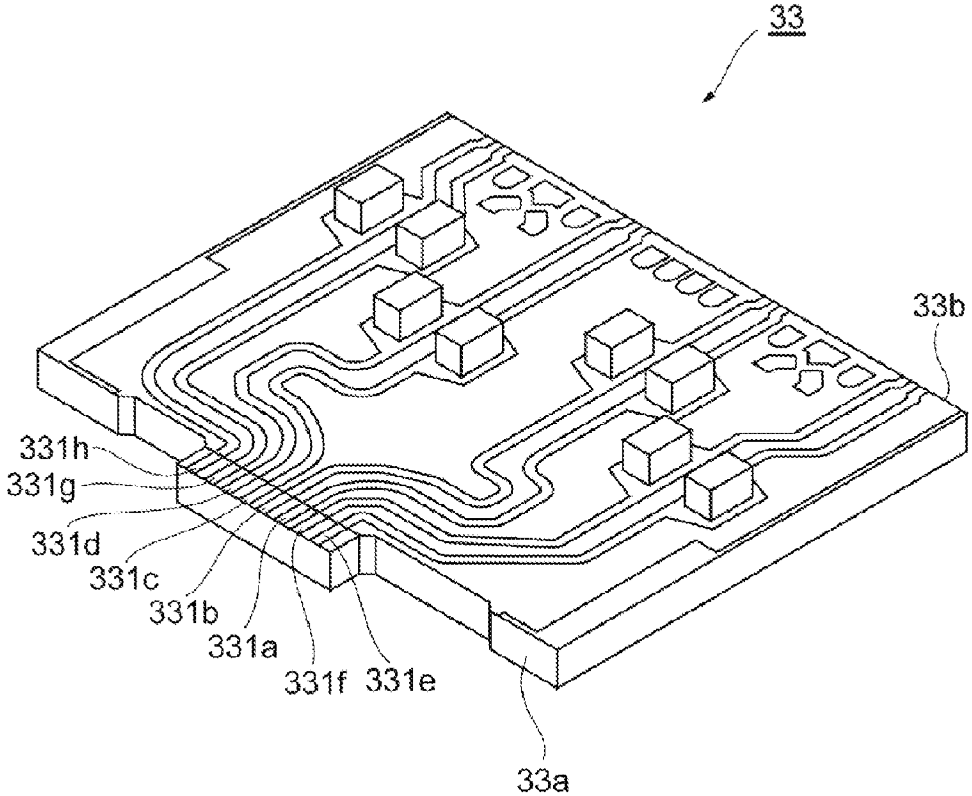
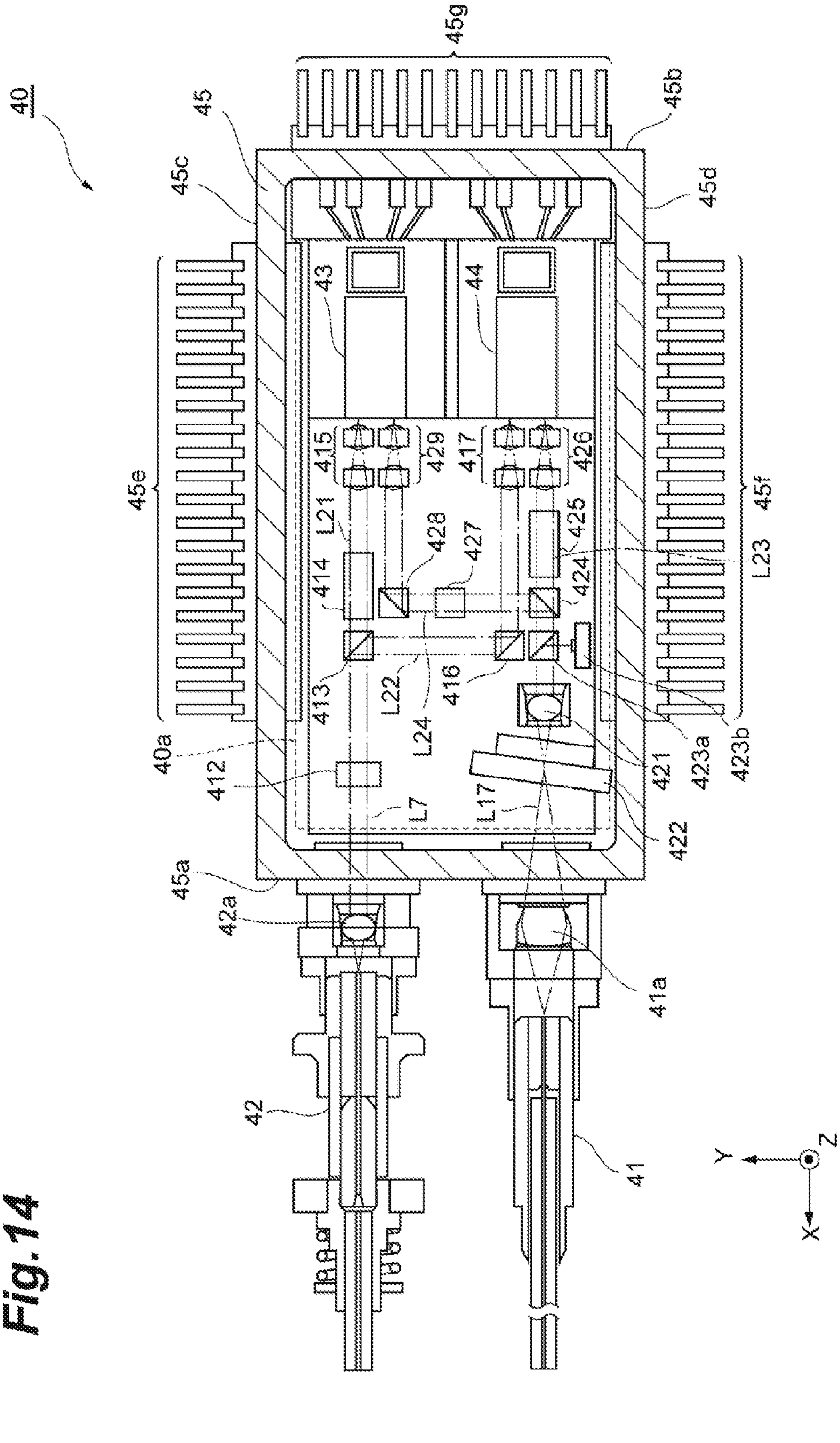
365i
365i
365h
32b

Fig.12

Fig.13

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413
L22
416
L24
423a
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Fig. 14

Fig.15A

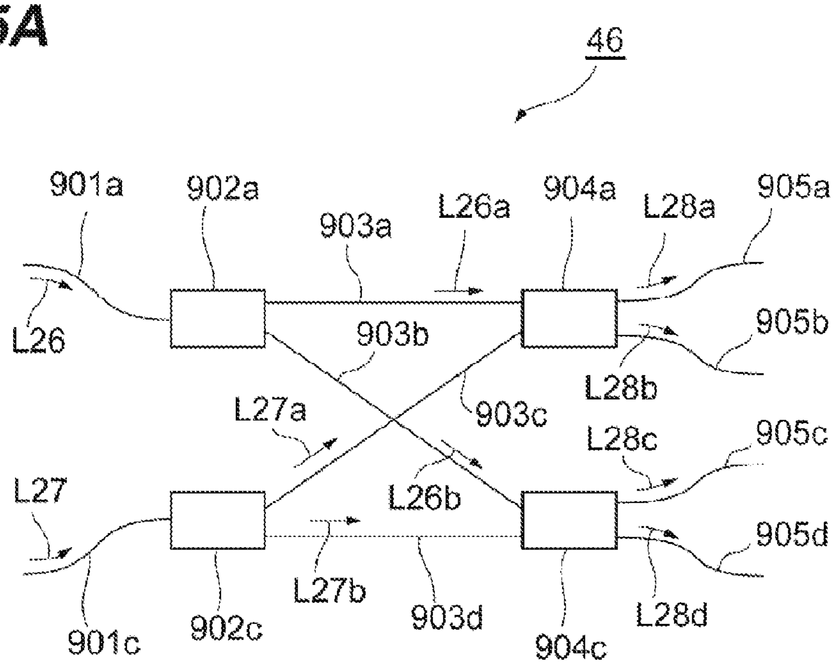


Fig.15B

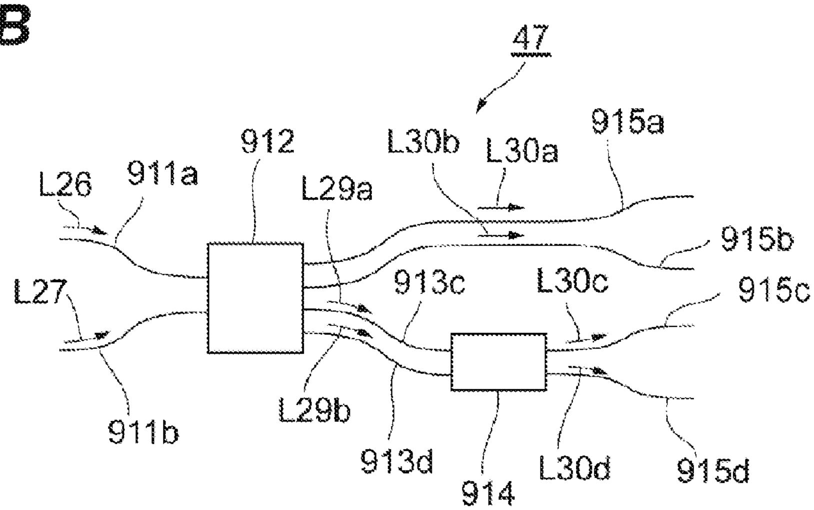
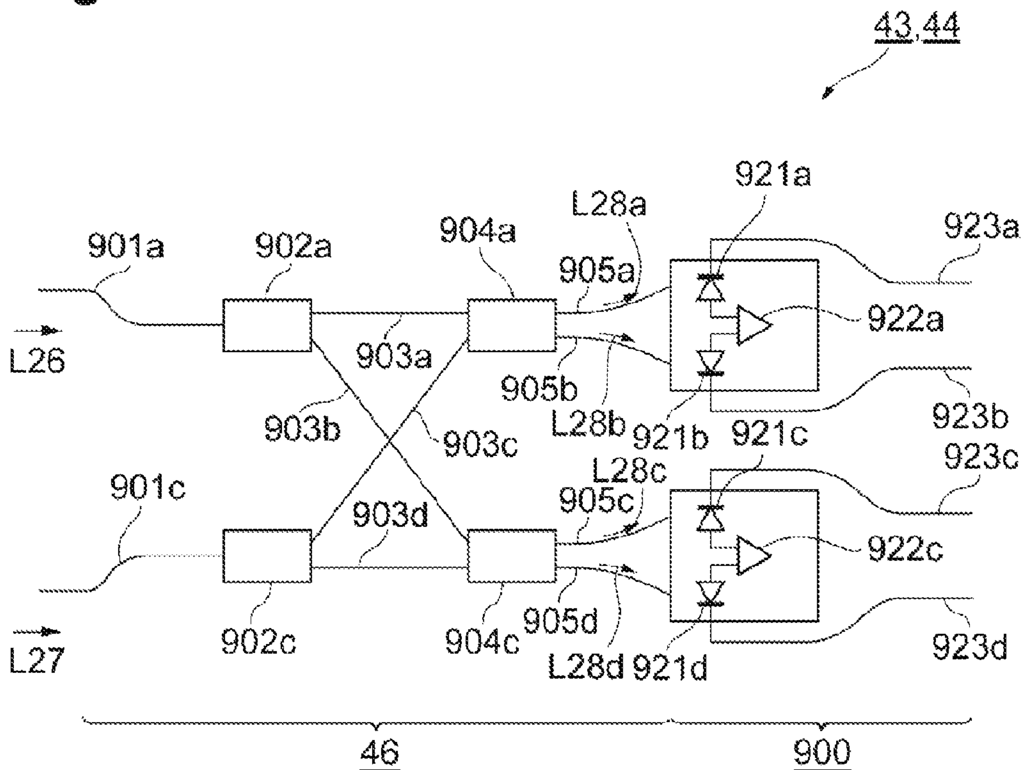


Fig.16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923c
L28c
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L27
46
900

Fig.17A

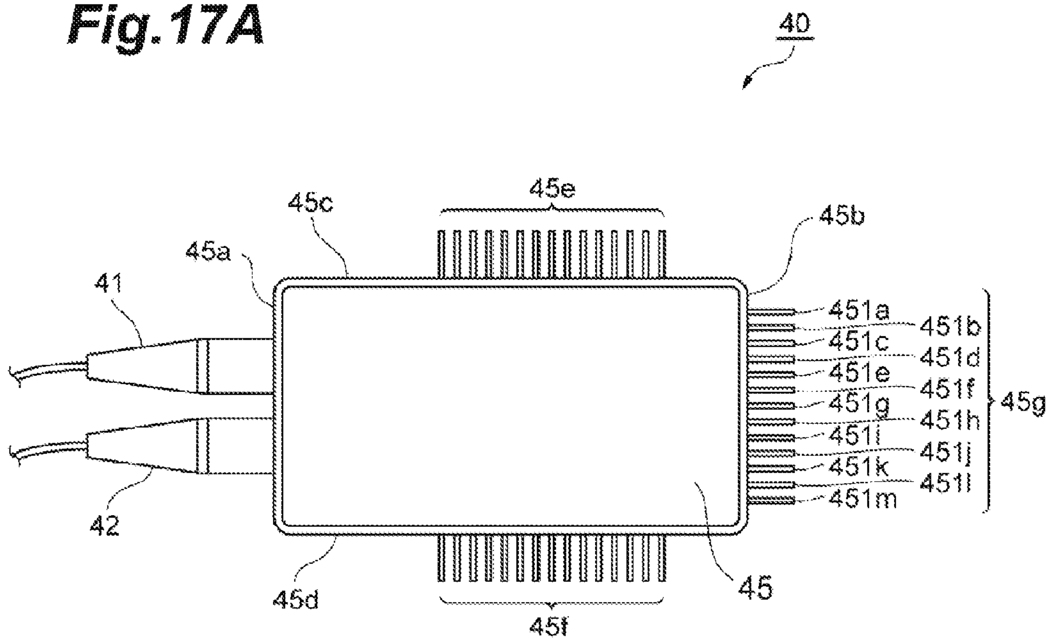
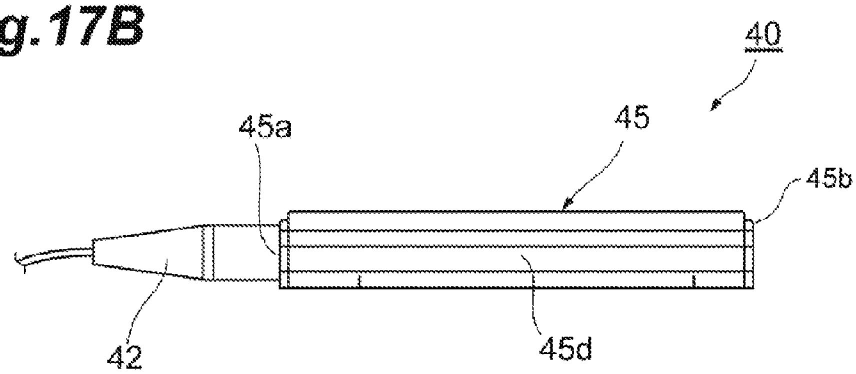


Fig.17B



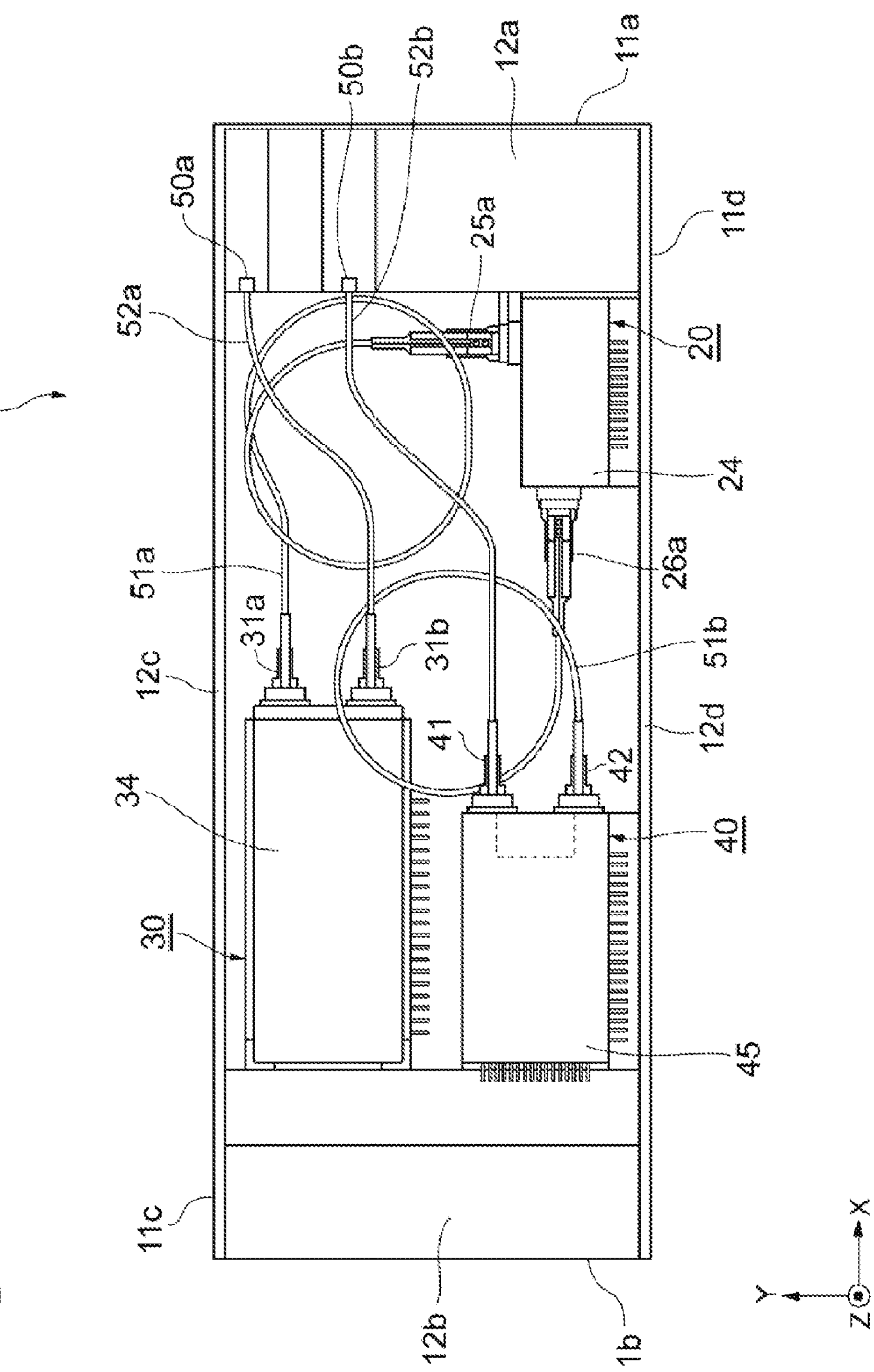

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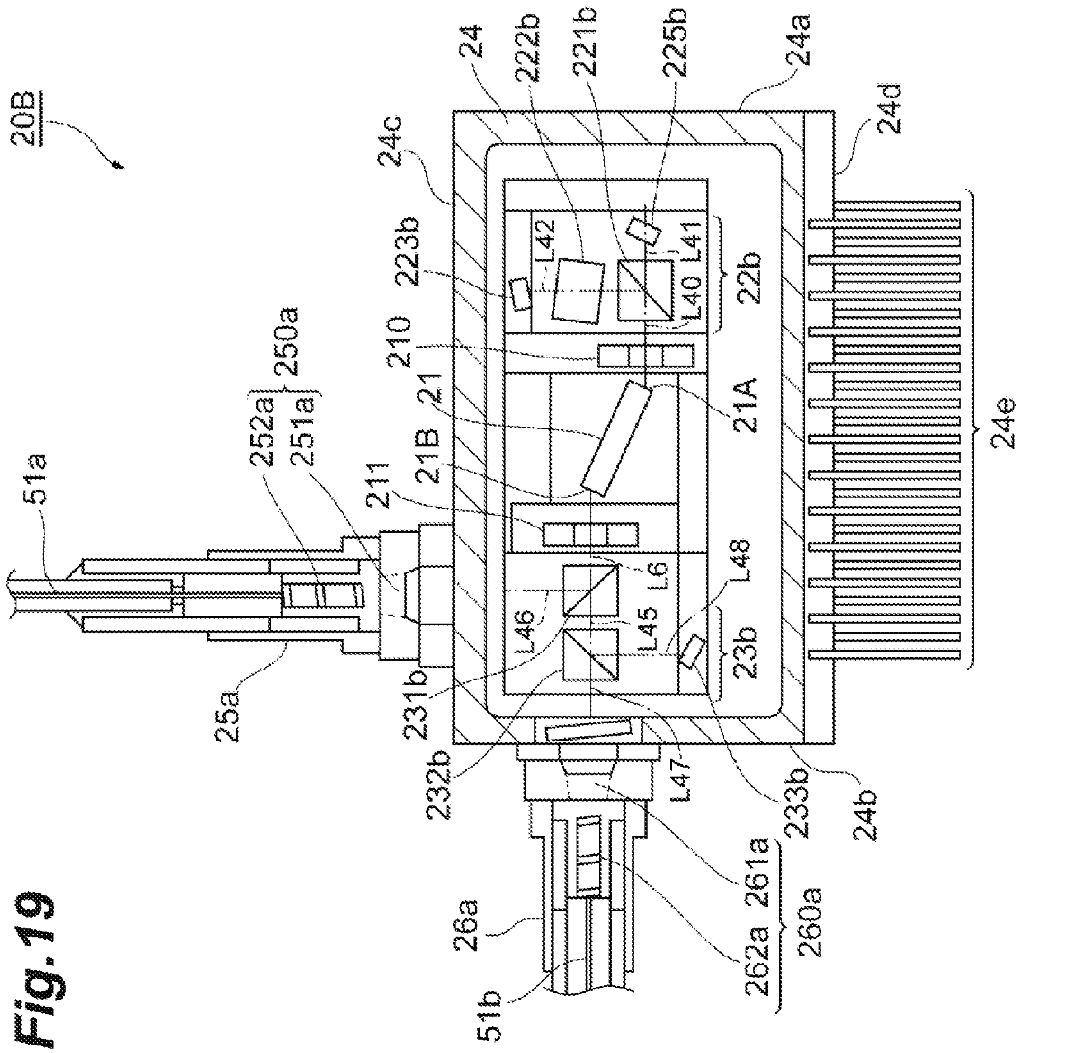
Fig.18



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51a
L6
L48
L46
L45
23b
24e
25a
231b
232b
L47
233b
24b
261a
260a
262a
26a
51b

Fig.19

FULL-DUPLEX OPTICAL TRANSCEIVER APPLICABLE TO DIGITAL COHERENT SYSTEM

TECHNICAL FIELD

The present application relates to an optical transceiver with the full-duplex configuration, in particular, the present application relates to a full-duplex optical transceiver applicable to the digital coherent system.

BACKGROUND

One type of optical modulations has been knows as, what is called, quadrature amplitude modulation (QAM). A United States Patent, US 2009/244685A, has disclosed an optical modulator to modulate an optical signal by the QAM configuration. Another United States Patent, US 2008/232816A, has disclosed a transmitter module and a receiver module for an optical communication system with a polarization multiplexed configuration. Still another United States Patent, US 2012/148235A, has disclosed a control circuit for a transmitter module and a receiver module implemented within in the digital coherent system.

The digital coherent system has been known as a technique to enhance the transmission capacity. When an optical transceiver with the full-duplex function is implemented within the digital coherent system, various subjects are to be solved. That is, the coherent system not only requires an optical source to generate optical signals but inevitably requires another optical source, which is often called as a local source, in a receiver module. The requirement of two optical sources makes the optical transceiver with the full-duplex function hard to be formed in compact. For example, one standard relating to a housing, which is known as the "CFP2" standard, are quite hard to install two optical sources, an optical modulator, a coherent receiver, and so on within one housing.

SUMMARY

An optical transceiver of the present application has a function of the full-duplex optical communication for a pair of optical fibers. The optical transceiver includes a wavelength tunable laser diode (LD), an optical transmitter, and an optical receiver. The optical transmitter output

an outgoing optical signal to one of the optical fibers by modulating a phase of an laser beam output from the wavelength tunable LD. The optical receiver receives an incoming optical signal from another of the optical fibers, where the incoming optical signal is modulated in the phase thereof, and extract data contained in the incoming optical signal by multiplexing the incoming optical signal with another of an laser beam also output from the wavelength tunable LD.

The wavelength tunable LD includes a pair of facets. One of facets outputs the laser beam for the optical transmitter; while, the other facets outputs the another laser beam for the optical receiver. In a modification, one of the facets outputs the laser beam for the optical transmitter and another of the laser beam for the optical receiver. Another of the facets may output an laser beam for tuning the wavelength of the laser beams.

The optical transceiver may further includes a laser module having a laser housing for enclosing the wavelength tunable LD, a transmitter module having a transmitter housing for enclosing the optical transmitter, and a receiver module having a receiver housing for enclosing the optical receiver, where the housings are separated from of each other.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other purposes, aspects and advantages will be better understood from the following detailed description of a preferred embodiment of the invention with reference to the drawings, in which:

FIG. **1** is a plain view showing an inside of an optical transceiver with the full-duplex function according to the first embodiment of the present invention;

FIG. **2** is a perspective view of the sub-modules, the optical receptacles, and the inner fibers each forming one loop between the modules;

FIG. **3** is an exploded view of the housing;

FIG. **4** illustrates the frame and the bottom cover assembled with the frame;

FIG. **5** views the inside of the housing that installs the laser module, the transmitter module, the receiver module, and the optical receptacles;

FIG. **6** is a cross section taken along the line VI-VI appearing in FIG. **5**;

FIG. **7** is a side view of the inside of the housing;

FIG. **8** is a plan view showing an inside of the laser module;

FIG. **9** is a side cross section of the laser module;

FIG. **10** schematically illustrates a structure of the tunable LD;

FIG. **11** is a plan view showing an inside of the transmitter module;

FIG. **12** is a plan view showing the optical modulator;

FIG. **13** is a perspective view showing the wiring substrate;

FIG. **14** is a plan view of an inside of the receiver module;

FIGS. **15**A and **15**B schematically show examples of the optical hybrids;

FIG. **16** shows a functional block diagram of a multi-mode interferometer;

FIGS. **17**A and **17**B show an outer appearance of the receiver module;

FIG. **18** is a plan view showing an inside of an optical transceiver according to the second embodiment; and

FIG. **19** is a plan view showing an inside of a laser module **20**B according to the third embodiment of the present invention.

DETAILED DESCRIPTION

Next, some embodiments of the present application will be described as referring to drawings. In the description of the drawings, numerals or symbols same with or similar to each other will refer to elements same with or similar to each other without duplicating explanations.

First Embodiment

FIG. **1** is a plain view showing an inside of an optical transceiver **10** with the full-duplex function according to the first embodiment of the present invention. As illustrated in FIG. **1**, the optical transceiver **10** includes a housing **11**, a laser module **20**, a transmitter module **30**, a receiver module **40**, and several inner fibers, **51***a* to **52***b*, optically coupling those sub-modules, **20** to **40**.

The housing **11** has a rectangular shape with a longitudinal direction along an axis X and a lateral direction along another axis Y, where the axes, X and Y, are indicated in FIG. **1**. The housing **11** provides a pair of sides, **11***a* and **11***b*, extending along the lateral direction Y, and another pair of sides, **11**c and **11**d, extending along the longitudinal direction X.

The housing **11** also provides a front block **12**a and an electrical plug **12**b. The front block **12**a forms the side **11**a and has a depth along the longitudinal direction X. The electrical plug **12**b forms another side **11**b and extends along the lateral direction Y. A side wall **12**c that forms the side **11**c and extends along the longitudinal direction X; and another side wall **12**d that forms the side **11**d and extends also along the longitudinal direction X. The front block **12**a has a pair of receptacles, **50**a and **50**b, the former of which is for the optical transmission, while, the latter is for the optical reception. The optical receptacles, **50**a and **50**b, may have an arrangement of the LC-type optical receptacle in the present embodiment. The optical transceiver **10** may perform the full-duplex communication through optical fibers each coupled with the optical receptacles independently.

The housing **11** shown in FIG. **1** follows the standard of the CFP2. Specifically, the housing **11** has a length of 106 mm along the longitudinal direction X, a width of 41.5 mm along the lateral direction Y, and a height of 12.4 mm along the direction Z. The dimensions described above involves the optical receptacles, **50**a and **50**b, and the electrical plug **12**b; accordingly, a space provided for sub-modules, **20** to **40**, is limited to about 75 mm along the longitudinal direction X. Thus, the sub-modules, **20** to **40**, are set within such a limited space, or, the optical transceiver following the CFP2 standard in the housing thereof is necessary to install sub-modules within a quite limited space.

The laser module **20**, which provides laser beams to the transmitter and receiver modules, **30** and **40**, is arranged close to the front block **12**a and the side wall **12**d. The laser module **20** includes a wavelength tunable LD and a laser housing **24** to install the wavelength tunable LD therein. The laser housing **24**, which has a rectangular shape with longitudinal sides along the direction X and lateral sides along the direction Y, provides a pair of sides, **24**a and **24**b, extending along the direction Y, and another pair of sides, **24**c and **24**d, extending along the direction X. The side **24**a faces the front block **12**a, while, the side **24**d faces the side wall **12**d. The present embodiment of the laser housing **24** provides lead terminals **24**e for DC and low frequency (LF) signals only in the side **24**d. The lead terminals **24**e electrically couples with the electrical plug **12**b through a circuit board, which is not shown in the figures.

The transmitter module **30** generates an outgoing optical signal to be transmitted from the optical transceiver **10** by modulating the laser beam output from the laser module **20**. The present embodiment disposes the optical transmitter **30** in a position close to the side wall **12**c and to the electrical plug **12**b. The transmitter module **30** provides a transmitter housing **34**, which is independent of the laser housing **24**, with a rectangular shape having longitudinal sides along the direction X and lateral sides along the direction Y. The transmitter housing **34** provides a pair of sides, **34**a and **34**b, extending along the direction Y, and another pair of sides, **34**c and **34**d, extending along the direction X. The side **34**c faces the side wall **12**c, while, the side **34**b faces the electrical plug **12**b. The transmitter housing **34** of the present embodiment has, what is called, a butterfly package with radio frequency (RF) terminals in the side **34**b, while, DC/LF terminals in the sides, **34**c and **34**d. These terminals are electrically connected to the electrical plug **12**b through a circuit board and/or a flexibly printed circuit board. The transmitter housing **34** may have dimensions, except for RF terminals and DC/LF terminals, of 37 mm×16.5 mm (L×W).

The receiver module **40** receives an incoming optical signal, whose phase is modulated and sometimes the amplitude thereof is also modulated, extracts data/information by multiplying the incoming optical signal with a laser beam output from the laser module **20**. The present optical transceiver **10** disposes the receiver module **40** close to the side wall **12**d and to the electrical plug **12**b. The transmitter and receiver modules, **30** and **40** are disposed in side by side along the direction Y in the present optical transceiver **10**. The receiver module **40** provides a receiver housing **45** independent of the laser housing **24** and the transmitter housing **34**. The receiver housing **45**, which has also a rectangular shape of a longitudinal direction along the direction X and a lateral direction along the direction Y, provides a pair of sides, **45**a and **45**b, extending along the direction Y, and another pair of sides, **45**c and **45**d, extending along the direction X. The side **45**d faces the side wall **12**d, while, the side **45**b faces the electrical plug **12**b. The receiver housing **45** may also have the butterfly package with RF terminals in the side **45**b and DC/LF terminals in the sides, **45**c and **45**d. The RF and DC/LF terminals are electrically coupled with the electrical plug **12**b through the circuit board or the flexible printed circuit board.

The inner fiber **51**a transmits the laser beam to the transmitter module **30** from the laser module **20**. The inner fiber **51**a in one end thereof optically couples with one of the output ports **25**a provided in the side **24**c of the laser housing **24**, while, couples with the input port **31**a provided in the side **34**a of the transmitter housing **34**. Another inner fiber **51**b, which is the second inner fiber in the present embodiment, transmits the laser beam generated in the laser module **20** to the receiver module **40**. The inner fiber **52**b in one end thereof couples with the other output port **26**a provided in the side **24**b of the laser housing **24**, while, anther end thereof couples with one of the input ports **42** provided in the side **45**a of the receiver housing **40**. These two fibers, **51**a and **51**b, are the polarization maintaining fiber to maintain the polarization direction of the laser beams.

The laser housing **24** of the present embodiment provides the output port **25**a in the side **24**c along the lateral direction X, while, the other output port **26**a in the side **24**b along the longitudinal direction Y. The first inner fiber **51**a extends from the laser module **20** along the first direction (Y direction), and the second inner fiber **51**b extends from the laser module **20** along the second direction (X direction) perpendicular to the first direction.

Moreover, the first and second inner fibers, **51**a and **51**b, of the present embodiment each have at least one loop. That is, the second inner fiber **51**b, which is pulled out from the output port **26**a of the laser module **20**; extends to a rear portion of the optical transceiver **10** along the side wall **12**d; turns by about 180° in the rear portion to head to the front portion of the housing **11**; extends to the other side **12**c; turns again by about 180° in the front portion so as to align the axis thereof with the axis of the input port **42**, and couples with the input port **42**. Similarly, the first inner fiber **51**a, which is pulled out from the output port **25**a; extends to the other side wall **12**c; turns by about 90°; extends along the side wall **12**c toward the rear portion; turns by about 180° at the rear portion toward the front portion; extends along the other side wall **12**d; and turns again by about 180° in the front portion so as to align the axis thereof with the input port **31**a of the transmitter housing **34**, and couples with the input port **31**a.

Thus, the first inner fiber **51**a forms a large single loop to touch, or almost touch the sides walls, **12**c and **12**d, in the lateral direction Y; while, to reach respective center portions of the transmitter housing **34** and the receiver housing **45** in the longitudinal direction X. Similarly, the second fiber **51**b forms a large single loop to touch, or almost touch the side walls, **12**c and **12**d, in the lateral direction Y, while, to exceed or over the transmitter housing **34** and the receiver housing **45** in the longitudinal direction X.

The input port **31**a of the transmitter housing **34** and the input port **42** of the receiver housing **45** each provides a polarization maintaining connector. Accordingly, the inner fibers, **51**a and **51**b, may be detachable with the input ports, **31**a and **42**, which enhances the productivity of the optical transceiver **10**. Specifically, the transmitter and receiver modules, **30** and **40**, may be facilitated to be installed within the space of the optical transceiver **10**, and the inner fibers, **51**a and **51**b, become easy to be disposed. The inner fiber **51**a shown in FIG. **1** is connected to the input port **31**a with a substantial angle. However, extending the inner fiber **51**a further toward the front portion exceeding the laser housing **24**, or almost touching the front block **12**a, the inner fiber **51**a may be connected to the input port **31**a straightforwardly.

Another inner fiber **52**a transmits the outgoing optical signal output from the transmitter module **30** to the transmitter optical receptacle **50**a. Specifically, one end of the inner fiber **52**a couples with the output **31**b provided in the side **34**a of the transmitter housing **34**, while, another one thereof is connected to the transmitter optical receptacle **50**a. Still another inner fiber **52**b transmits the incoming optical signal provided from an external optical fiber and output from the receiver optical receptacle **50**b to the receiver module **40**. Specifically, one end of the inner fiber **52**b is connected to the receiver optical receptacle **50**b, while, another end thereof is connected to the input port **41** provided in the side **45**a of the receiver housing **45**. The inner fibers, **52**a and **52**b, may be permanently connected to the transmitter receptacle **50**a, the receiver optical receptacle **50**b, the output port **31**b, and the input port **41**.

The embodiment shown in FIG. **1** connects the optical receptacles, **50**a and **50**b, to the output port **31**b and the input port **41** by the inner fibers, **52**a and **52**b, with respective shortest length. However, similar to the inner fibers, **51**a and **51**b, the inner fibers, **52**a and **52**b, may have at least one loop between respective ends. For instance, as shown in FIG. **2**, which is a perspective view of the modules, **20** to **40**, the optical receptacles, **50**a and **50**b, and the inner fibers, **51**a to **52**b, but omits the housing **11**; the inner fibers, **52**a and **52**b, form a loop between respective two ends. The inner fiber **52**a, which is pulled out from the transmitter optical receptacle **50**a, extends along the side **12**c to the rear, turns by about 180° in the rear, extends along the other side **12**d to the front, and turns again by 180° in the front so as to align the axis thereof with the axis of the output port **31**b, and reaches the output port **31**b. The other inner fiber **52**b, which is pulled out from the receiver receptacle **50**b, extends along the side **12**c toward the rear, turns by about 180° in the rear, extends along the other side **12**d toward the front, and turns again by about 270° in the front so as to align the axis thereof with the axis of the input port **41**, and reaches the input port **41**.

In the arrangement of the inner fibers, **51**a to **52**b, the inner fiber **52**b shows the minimum curvature in a portion to turn about 270° in the front and to form an S-like shape subsequent to the portion above. However, the inner fibers, **51**a to **52**b, may secure the minimum curvature of at least 15 mm.

Next, the inner structure of the optical transceiver **10** will be further described. FIG. **3** is an exploded view of the housing **11**, where FIG. **3** omits the inner fibers, **51**a to **52**b. The housing **11** primarily comprises a frame **71**, a bottom plate **72**, a bottom cover **73**, a printed circuit board (PCB) **74**, and a top cover **75**. The frame **71** mounts the laser module **20**, the transmitter module **30**, and the receiver module **40**. The bot-

tom plate **72**, which is made of metal and assembled with the frame **71** to support the bottom side of the frame **71**, has square openings, **72**a to **72**c, each corresponding to the laser module **20**, the transmitter module **30**, and the receiver module **40**. The bottom cover **73**, which is made of metal, is assembled with the bottom plate **72** so as to cover the square openings, **72**a to **72**c. The laser module **20**, the transmitter module **30**, and the receiver module **40** are in contact to the bottom cover **73** as passing respective square openings, **72**a to **72**c, to enhance the heat dissipating.

In an optical transceiver, a transmitter module electrically switches a large current to drive an optical device, typically a semiconductor laser diode, which affects an operation of an optical receiver that converts a weak optical signal into a weak electrical signal. Accordingly, the transmitter module preferably isolates the ground thereof from the ground of the receiver module. The present optical transceiver **1** isolates the receiver housing **45** electrically form the frame **71** by interposing an insulating holder therebetween. Also, the receiver housing **45** is made of material having good thermal conductivity and is in thermally contact with the bottom cover **73** by interposing a thermal sheet, or, a heat-dissipating sheet.

The PCB **74** mounts electronic circuits thereon. The PCB **74** longitudinally extends from the laser module **20** in the front to the transmitter module **30** and the receiver module **40** in the rear **40**. Also, the PCB **74** provides interconnections to be connected to the DC/LF terminals of the laser module **20**, and the DC/LF terminals of the transmitter module **30** and the receiver module **40**. The PCB **74** is electrically connected to the electrical plug **12**b through a relay board **76**, which is shown in FIG. **5**. The top cover **75** is made of metal, and covers and electrically shields the PCB **74**, the laser module **20**, the transmitter module **30**, and the receiver module **40**.

FIG. **4** illustrates the frame **71** and the bottom cover **72**. The frame **71**, which may be formed by, for instance, metal die-casting, provides a front pocket **71**a where the optical receptacles, **50**a and **50**b, is set and a rear pocket **71**b where the electrical plug **12**b is set. The frame **71** further provides a center beam **71**c, timbers **71**g laterally extending from the beam **71**c, and three openings, **71**d to **71**f, surrounded and formed by the beam **71**c and the timbers **71**g. Each of openings, **71**d to **71**f, corresponds to respective square openings, **72**a to **72**c, of the bottom plate **72**. The openings, **71**d to **71**f, have dimensions greater than the dimensions of the square openings, **72**a to **72**c. Accordingly, the square openings, **72**a to **72**c, are exposed within the openings, **71**d to **71**f. The frame **71** preferably provides the beam **71**c whose height or thickness is greater than the thickness of the timbers **71**g to secure the stiffness of the frame **71**.

FIG. **5** views the inside of the housing **11** that installs the laser module **20**, the transmitter module **30**, the receiver module **40**, and the optical receptacles, **50**a and **50**b, in respective positions, but FIG. **5** omits the PCB **74**. The transmitter and receiver modules, **30** and **40** implement flexible printed circuit boards (FPC boards). FIG. **6** is a cross section taken along the line VI-VI appearing in FIG. **5**. FIG. **7** is a side view of the inside of the housing **11**.

As illustrated in FIGS. **5** to **7**, the FPCs, **77**a to **77**b, electrically connect the DC/LF terminals, **34**e and **34**f, provided in respective sides, **34**c and **34**d, of the transmitter module **30** to the PCB **74**. Other FPCs, **77**c and **77**d, electrically connect the DC/LF terminals, **45**e and **45**f, provided in respective sides, **45**c and **45**d, of the receiver module **40** to the PCB **74**. Further, the FPC **77**h electrically connects the DC/LF terminals **24**e provided in the side **24**d of the laser module **20** to the

PCB **74**. Finally, the PCB **74** is electrically connected to the electrical plug **12***b* through the FPC **77***g* and the relay board **76**.

On the other hand, the RF terminals provided in the side **34***b* of the transmitter module **30** is directly connected to the relay board **76** with an FPC **77***e* as illustrated in FIG. **7** without passing the PCB **74**. Similarly, the RF terminals provided in the side **45***b* of the receiver module **40** is directly connected to the relay board **76** with an FPC **77***f* without passing the PCB **74**. Thus, the RF terminals are directly connected to the relay board **76**.

An optical transceiver for the digital coherent system usually processes high frequency signals over 10 GHz. Such signals are readily degraded during the transmission. Accordingly, in the optical transceiver of the embodiment, the transmitter module **30** and the receiver module **40** provide RF terminals only in respective sides, **34***b* and **45***b*, facing the electrical plug **12***b* to transmit RF signals directly to/from the relay board **76** without passing the PCB **74**. This arrangement makes the transmission paths for the RF signals short enough compared with an arrangement interposing the PCB **74**. Moreover, the present arrangement may reduce the count of nodes or points at which the transmission impedance is disarranged. The DC/LF terminals, **34***e*, **34***f*, **45***e*, and **45***f*, are connected to the electrical plug **12***b* through the PCB **74**. Signals for DC/LF terminals are substantially independent of the length of the transmission line and the number of the nodes in the transmission line.

The present embodiment makes the laser housing **24**, the transmitter housing **34** and the receiver housing **45** in thermally and physically contact to the bottom cover **73** to conduct heat. Accordingly, no spaces are secured between those housing, **24**, **34**, and **45**, and the bottom cover **73** for the inner fibers, **51***a* to **52***b* to go through. The inner fibers, **51***a* to **52***b*, are set between respective housings, **24**, **34**, and **45**, and the top cover **75**. Because the PCB **74** and the FPCs, **77***a* to **77***d*, are set between the housings, **24**, **34**, and **45**, and the top cover **75**, the inner fibers, **51***a* to **52***b*, are necessary to be set in this space so as not to interfere with the PCB **74** and the FPCs, **77***a* to **77***d*.

First, the FPCs, **77***a* to **77***d*, are set in this space as follows. That is, as illustrated in FIG. **6**, two FPCs, **77***a* and **77***d*, connected to the DC/RF terminals in respective sides, **34***c* and **45***d*, close to the sides walls, **12***c* and **12***d*, extend upward, bent by about a right angle, and soldered to the top surface of the PCB **74**. The other FPCs, **77***b* and **77***c*, connected to respective sides, **34***d* and **45***c*, positioned in a center of the housing **11**, are also extended upward, bent by about a right angle at the corners of respective housings, **34** and **45**, extended in the space between the housings, **34** and **45**, and the bottom surface of the PCB **74** to respective side walls, **12***c* and **12***d*, folded at respective edges of the PCB **74**, and finally soldered on the top of the PCB **74**.

Moreover, as illustrated in FIG. **5**, the first group of FPCs, **77***b* and **77***d*, are connected to the PCB **74** in a portion close to the electrical plug **12***b*; while, the second group of FPCs, **77***a* and **77***e*, are connected to a portion of the PCB **74** close to the laser module **20**. Thus, four FPCs, **77***a* to **77***d*, are set so as not to interfere with others. The combination of the groups for the FPCs, **77***a* to **77***d*, is optional. For instance, an arrangement where two FPCs, **77***a* and **77***d*, are connected to the front portion, while, the rest FPCs, **77***b* and **77***c*, are connected to the rear portion, may be also applicable in the optical transceiver **10**.

The optical transceiver **10** of the embodiment providing the arrangement for the FPCs, **77***a* to **77***d*, described above makes a space between respective modules, **30** and **40**, and the PCB **74** enough to set the inner fibers, **51***a* to **52***b*, therein as forming at least one loop. This space preferably has a depth, namely, a distance between the top of the modules, **30** and **40**, and the bottom surface of the PCB **74**, of at least twice of the outer diameter of the inner fibers, **51***a* to **52***b*. Such depth makes it possible to cross the inner fibers, **51***a* to **52***b*, without causing any stress to the inner fibers, **51***a* to **52***b*.

The description above concentrates an arrangement for the FPCs, **77***b* and **77***c*, connected to respective center sides, **34***d* and **45***c*, of the modules, **30** and **40**, are set in contact to the top of the modules, **30** and **40**. However, the FPCs, **77***b* and **77***c*, may be set so as to be in contact with the bottom surface of the FPC **74**. Although the FPCs, **77***b* and **77***c*, block a portion of the center of the space in this modified arrangement, the inner fibers, **51***a* to **52***b*, may be set in another space between the modules, **30** and **40**, and the electrical plug **12***b* so as to avoid the FPCs, **77***b* and **77***c*, in the center. Moreover, this arrangement of the FPCs, **77***b* and **77***c*, may temporarily arrange the inner fibers, **51***a* to **52***b*, by the FPCs, **77***b* and **77***c*, during the assembly of the optical transceiver **10**.

Next, details of the laser module **20**, the transmitter module **30**, and the receiver module **40** are explained.

(Laser Module)

FIG. **8** is a plan view showing an inside of the laser module **20**. The laser module **20** installs a wavelength tunable LD **21** that provides two facets **21**A and **21**B forming an optical cavity. The laser module **20** further includes a wavelength locker **22***a* optically coupled with the facet **21**A and an optical system **23***a* including a beam splitter (BS) **231***a* coupled with the other facet **21**B. The wavelength locker **22***a* and the optical system **23***a* are enclosed within the laser housing **24**.

The wavelength locker **22***a* includes a BS **221***a*, an etalon filter **222***a*, and photodiodes (PDs), **223***a* and **225***a*. A laser beam L1 output from the facet **21**A, which is often called as a back-facet beam, is collimated by a lens **210**, and split by the BS **221***a* into two beams, L2 and L4. One of the beams L4, which is split and bent by a right angle by the BS **221***a*, passes the etalon filter **222***a* and enters the PD **223***a*. The etalon filter **222***a* inherently shows a wavelength dependent transmittance. The other beam L2, which passes the BS **221***a*, is split again into two beams, L3 and L5, by the BS **224***a*. One of the beams L3, bent by a right angle by the BS **224***a*, enters the inner fiber **51***a* passing the output port **25***a*, while, the other beam L5 enters the PD **225***a*.

The wavelength of the laser beam L1 emitted from the wavelength tunable LD **21** may be determined by a ratio of two beams, L4 and L5, that is, the ratio of the photocurrents, I1*a* and I2*a*, namely, I1*a*/I2*a*, each proportional to the magnitude of the beams, L4 and L5, and detected by respective PDs, **223***a* and **225***a*, denotes the transmittance of the etalon filter **222***a*. Accordingly, measuring the wavelength dependence of the transmittance of the etalon filter **222***a* and comparing the ratio of two beams, L4 and L5, the wavelength of the laser beam L1 output from the wavelength tunable LD **21** may be determined. In the embodiment, the ratio I1*a*/I2*a* is fed back to the driver for the thermo-electric cooler (TEC), on which the wavelength tunable LD **21** is mounted, or the driver for the wavelength tunable LD **21** that adjusts the driving currents provided to the wavelength tunable LD **21**. The temperature of the tunable LD **21**, and various elements and parameters of the wavelength tunable LD **21** are adjusted such that the wavelength of the wavelength tunable LD **21** becomes the target wavelength.

The output port **25***a* includes an optical coupling unit **250***a* having a focusing lens **251***a* and an optical isolator **252***a*. The isolator **252***a* prevents light from returning to the wavelength tunable LD **21**. Light entering the cavity of the wavelength tunable LD **21** behaves as optical noise sources, which drastically degrades the quality of the laser beam output from the wavelength tunable LD **21**. The focusing lens **251***a* in the coupling unit **250***a* enhances the optical coupling efficiency of the beam L3 with the inner fiber **51***a*.

The optical system **23***a* includes a BS **231***a* and the PD **232***a*. The laser beam L6 output from the facet **21**B of the wavelength tunable LD **21**, which is often called as the front facet, and collimated by the collimating lens **211**, is split into two beams, L7 and L8. One of the beams L7, which passes the BS **231***a*, enters the inner fiber **51***b* as passing through the output port **26***a*. The other beam L8, which is bent by a right angle by the BS **231***a*, enters the PD **232***a*. Accordingly, the PD **232***a* monitors the magnitude of the laser beam L6 output from the front facet **21**B of the wavelength tunable LD **21**.

The output port **26***a* provides an optical coupling unit **260***a* having a focusing lens **261***a* and an optical isolator **262***a*. The optical isolator **262***a*, same as that **252***a* provided in the other coupling unit **250***a*, prevent light generated in outsides of the laser module **20** from returning the tunable LD **21**. The focusing lens **261***a* enhances the optical coupling efficiency of the outgoing beam L7 with the inner fiber **51***b*.

FIG. **9** is a side cross section of the laser module **20**. The laser module **20** of the embodiment provides, the TEC **28**, and a base **29** mounted on the top plate **28***a*. The base **29** mounts the tunable LD **21**, the wavelength locker **22***a* and the other optical system **23***a*. The base **29**, which has an area wider than an area of the top plate **28***a* of the TEC **28**, extends from the edges of the top plate **28***a* of the TEC **28**. The wavelength tunable LD **21** is mounted in a center area of the base **29** overlapping the top plate **28***a*, while, the wavelength locker **22***a* and the optical system **23***a* are placed in respective areas extending from the edges of the top plate **28***a*. Accordingly, the TEC **28** primarily controls a temperature of the tunable LD **21**. The wavelength locker **22***a* and the optical system **23***a* have relatively dull temperature dependence, and show enough performance without controlling the temperature thereof by the TEC **28**. Moreover, a narrowed top plate **28***a* of the TEC **28** results in a lesser number of Peltier elements, which reduces the price/cost of the TEC **28**.

FIG. **10** schematically illustrates an inner structure of the wavelength tunable LD **21**. The wavelength tunable LD **21** of the embodiment provides three sections, namely, a Chirped Sampled Grating-Distributed Bragg Reflector (CSG-DBR) section **212***a*, a Sampled-Grating Distributed Feedback (SG-DFB) section **213***a*, and a semiconductor optical amplifier (SOA) section **214***a*, arranged in this order along an optical axis of the wavelength tunable LD **21**. In a modification, an additional section of a back absorber (BA) may be formed between the CSG-DBR section **212***a* and one of the facets **21**A.

The CSG-DBR section **212***a* inherently shows a reflectance spectrum with a plurality of reflection peaks; while, the SG-DFB section **213***a* inherently shows an optical gain spectrum with a plurality of gain peaks. A span between the nearest reflection peaks and a span between the nearest gain peaks are slightly different from others. Modifying the refractive indices of respective sections, **212***a* and **213***a*, respective spans and positions of the reflection peaks and the gain peaks are adjustable; and the laser oscillation occurs at a wavelength where one of the reflection peaks becomes coincides with one of the gain peaks.

The CSG-DBR section **212***a* provides micro-heaters **212***b* to modify the temperature of micro areas in the CSG-DBR section **212***a*, which also modifies or varies the refractive index thereat to vary the span between the reflection peaks and the positions of the reflection peaks. On the other hand, the SG-DFB section **213***a* provides gain areas **213***b* and modifying areas **213***c* alternately arranged to each other along the optical axis. Each of areas, **213***b* and **213***c*, provides electrodes, **213***d* and **213***e*, to inject currents. The current injected into the gain areas **213***b* generate photons, while, the current injected into the modifying areas **213***c* modifies the refractive index of the areas **213***c* to vary the span between the gain peaks and the positions thereof. Thus, varying the micro-temperature in the CSG-DBR section **212***a* and the refractive index of the modifying areas **213***c*, a wavelength, at which one of the reflection peaks attributed to the CSG-DBR section **212***a* and one of the gain peaks attributed to the SG-DFB section **213***a* matches, appears in a wavelength range. Accordingly, the emission wavelength of the tunable LD **21** may be varied continuously in this wavelength range.

The CSG-DBR section **212***a* provides a plurality of micro-heaters **212***b* whose temperatures are independently controllable. This arrangement of the micro-heaters **212***b* makes it possible to vary temperature distribution of the CSG-DBR section **212***a* widely and precisely. This means that the wavelength range within which the emission wavelength be tuned may be expanded. For instance, the dense wavelength division multiplexing (DWDM) standard defines the wavelength grids, namely, channel grids with a span of 50 GHz and the number of the wavelength grids of 100 grids in an wavelength range of 192 to 197 THz, which corresponds to the wavelengths of 1.55 μm band. In order to follow such a wide range of the emission wavelengths stably, the wavelength tunable LD **21** of the embodiment provides a plurality of micro-heaters **212***b*.

The laser module **20** of the embodiment extracts the laser beam L1 output from the facet **21**A through the wavelength locker **22***a*. The split ratio by the BS **221***a* is preferably determined by the ratio of respective outputs, I1*a* and I2*a*, of the PDs, **223***a* and **225***a*. The split ratio of the BS **221***a* is determined such that the laser beam L3 extracted from the output port **25***a* has magnitude enough to be processed in the transmitter module **30** and the laser beam L4 entering the PD **223***a* has magnitude to determine the emission wavelength.

(Transmitter Module)

FIG. **11** shows an inside of the transmitter module **30**. The transmitter module **30** of the embodiment provides an optical transmitter **30***a* with an optical modulator **32** made of semiconductor material, primarily InP in the present embodiment. A whole of the optical transmitter **30***a* is enclosed within the transmitter housing **34**. The optical modulator **32**, receiving the laser beam L3 output from the laser module **20**, generates two beams, L11 and L12, by modulating the laser beam L3. The optical modulator **32** has a rectangular plane shape with a longitudinal axis extending in parallel to the longitudinal axis of the module housing **34** and four sides, two of which, **32***a* and **32***b*, extends laterally with a length of 2.8 mm, while, other two sides, **32***c* and **32***d*, extends longitudinally with a length of 11 mm.

The optical transmitter **30***a* further includes a wiring substrate **33**, a mirror **301**, auxiliary substrates, **302***a* to **302***f*, and drivers, **308***a* to **308***d*.

The mirror **301** and the auxiliary substrates, **302***a* to **302***c*, are disposed in a side close to the side **32***c* of the optical modulator **32**; while, other auxiliary substrates, **302***d* to **302***f*, are disposed in a side close to the side **32***d* of the optical modulator **32**. The mirror **301** reflects the laser beam L3 coming from the input port **31***a* provided in the side **34***a* of the transmitter housing **34** toward the input port **35** provided in the side **32***c* of the optical modulator **32**. That is, an optical path from the input port **31***a* to the mirror **301** extends longitudinally, while, an optical path from the mirror **301** extends laterally. The auxiliary substrates, **302**a to **302**c, are arranged along the optical path from the input port **31**a to the mirror **301** but underneath the optical path so as not to interfere the laser beam L3. The input port **31**a provides an optical coupling system including a lens to collimate the light coming from the inner fiber **51**a.

The auxiliary substrates, **302**b and **302**c, and the auxiliary substrates, **302**e and **302**f, are electrically connected to the optical modulator **32**. The PDs are mounted on the auxiliary substrates, **302**b and **302**e, for detecting magnitude of the beam output from the optical modulator **32**. The auxiliary substrates, **302**c and **302**f, provide interconnections on the surfaces thereof to transmit DC/LF signals from the DC/LF terminals, **34**e and **34**f, to the optical modulator **32**. The DC/LF terminals, **34**e and **34**f, of the transmitter module **30** are not directly connected to the optical modulator **32** with bonding wires but through the interconnections on the auxiliary substrates, **302**c and **302**f. The DC/LF terminals, **34**e and **34**f, are wire-bonded to the interconnections on the auxiliary substrates, **302**c and **302**f, in one ends thereof, and the interconnections in the other end thereof are wire-bonded to the optical modulator **32**. This arrangement of the auxiliary substrates, **302**c and **302**f, may avoid the interference of bonding wires with the laser beam L3 coming from the input port **31**a.

The optical transmitter **30**a further includes an output coupling system including a half-wave (λ/2) plate **303**, a polarization beam combiner (PBC) **304**, a BS **306**, a mirror **305**, and a PD **307** between the side **32**a of the optical modulator **32** and the side **34**a of the transmitter housing **34**. The side **32**a of the optical modulator **32** provides two output ports, **37**a and **37**b, to output the first modulated beam L11 and the second modulated beam L12, respectively. These two laser beams, L11 and L12, are converted into collimated beams by respective two lenses disposed in front of the output ports, **37**a and **37**b.

One of the modulated beams L11 is bent by the mirror **305** to reach the PBC **304**. The other of the modulated beams L12 output from the port **37**b and converted into the collimated beams passes the half-wave plate **303** to rotate the polarization direction thereof by 90° and reaches the PBC **304**. That is, two modulated beams, L11 and L12, have respective polarization directions perpendicular to the other at the PBC **304**. Accordingly, the PBC may combine two modulated beams to form the combined modulated beam L13. A portion of the combined modulated beam L13 is spilt by the splitter **306** to be detected by the PD **307**, while, a primary portion of the beam L13 is output from the output port **31**b to the inner fiber **52**a. The PD **307** may detect total magnitude of the output beam L13.

In the arrangement of the output optical system described above, the half-wave plate **303** is set for the laser beam L12 not bent by the mirror **305**. When the half-wave plate **303** is set for the other laser beam L11 to be bent by the mirror **305** toward the PBC **304**, the optical skew inevitably increases depending on the path lengths of respective beams, L11 and L12. An additional means to compensate the optical skew is necessary to be set in the path for the laser beam L12.

The wiring substrate **33**, which is put adjacent to the side **32**b of the optical modulator **32**, electrically connects the drivers, **308**a to **308**d, with the optical modulator **32**. The drivers, **308**a to **308**d, are electrically connected to the RF terminals **34**g provided in the side **34**d of the transmitter housing **34**. The drivers, **308**a to **308**d, generate driving signals to drive the optical modulator **32** based on modulation signals provided to the RE terminals **34**g. An area **38** surrounded by a broken line appearing in FIG. **11** corresponds to a plane shape of a TEC.

FIG. **12** is a plan view of the optical modulator **32**. The optical modulator **32** has the type of the four Mach-Zehnder (MZ) modulators including eleven (11) 1×2 couples, **361**a to **361**k, two 2×2 couples, **361**m and **361**n, eight (8) arm waveguides, **363**a to **363**h, interconnections, **365**a, **365**h, ground interconnections **365**i, modulation electrodes, **362**a to **362**h, bias electrodes, **368**a to **368**m, and ground electrodes **362**i. The seven (7) 1×2 couples, **361**a to **361**g, are placed in three levels to split the input beam provided from the input port **35** in the side **32**c into eight (8=23) beams, where they are grouped into four (4) pairs each propagating within the arm waveguides, **363**a to **363**h.

The arm waveguides, **363**a to **363**h, where they longitudinally extend along the X-direction, provide respective modulation electrodes, **362**a to **362**h, and respective pairs of the arm waveguides, **363**a to **363**h, put the ground electrode **362**i therebetween. The modulation electrodes, **362**a to **362**h, are connected to the interconnections, **365**a, **365**h, while, the ground electrode **362**i is connected to the ground **365**i. These interconnections, **365**a, **365**h, and the ground **365**i in respective one ends thereof receive the modulation signals from the drivers, **308**a to **308**d, at the side **32**b. The other ends of the interconnections, **365**a, **365**h, are drawn to respective electrodes, **366**a and **366**b, at the sides, **32**c and **32**d, and connected to respective terminators mounted on the substrates, **302**b and **302**e, where they are placed adjacent to respective sides, **32**c and **32**d, as shown in FIG. **11**.

The bias electrodes, **368**a to **368**h and **368**i to **368**m are provided with DC biases through interconnections, **367**a and **367**b, drawn to respective sides, **32**c and **32**d. The bias electrodes, **368**a to **368**m, receive the bias to adjust the phases of the beams propagating in respective waveguides. Specifically, the bias electrodes, **368**a and **368**b, provided in the arm waveguides, **363**a and **363**b, generate the phase offset between the beams each propagating in the arm waveguides, **363**a and **363**b. The modulation signal provided from the driver **308**a includes two signals complementary to each other and has amplitude to delay the phase of the beam propagating in the arm waveguide under the modulation electrode by π. The bias electrodes, **368**a and **368**b, are provided with biases to cause the phase offset of π between two beams each propagating in the arm waveguides, **363**a and **363**b, where the beam propagating in the arm waveguide **363**a is assumed to be delayed by π against the other beam propagating in the other arm waveguides, **363**b. Then, when the modulation electrode **362**a receives the modulation signal with the maximum amplitude and the modulation electrode **362**b receives the signal with the minimum amplitude or substantially zero level, the beam propagating in the arm waveguide **363**a is delayed by π but the other beam propagating in the other arm waveguide **363**b is left unchanged. Thus, the beam propagating in the arm waveguide **363**a is delayed against the other beam in the arm waveguide **363**b by π+π=2π, and the beam combined by the 1×2 coupler **361**i has the phase delay of zero.

On the other hand, when the modulation signal applied to the modulation electrode **362**a becomes the minimum or zero, while, the other modulation signal applied to the other electrode **362**b becomes the maximum, the offset bias applied to the bias electrode **368**a only contributes the phase delay of the beam propagating in the arm waveguide **363**a, which becomes π. The beam propagating in the other arm waveguide **363**b is delayed by the modulation signal **365**b by π. Thus, the beam combined by the 1×2 coupler **361**i has the phase delay of π. Accordingly, the differential modulation signal applied to the modulation electrodes, **362**a and **362**b, and the offset bias applied to the bias electrodes, **368**a and **368**b, may modulate the phase of the beam split by the 1×2 couplers, **361**a,

361*b* and **361***d*, and combined by the 1×2 coupler **361***i*. Other pairs of the arm waveguides, **363***c* and **363***d*, **363***e* and **363***f*, **363***g* and **363***h*, accompanied with respective modulation electrodes, **362***c* to **362***h*, and the bias electrodes, **368***c* to **368***h*, show the same function described above. Thus, the optical modulator **32** may generate four optical signals each modulated by respective modulation signals provided from the drivers, **308***a* to **308***d*.

The beams combined by the 1×2 couplers, **361***i* and **361***h*, are further offset by the signals applied to the bias electrodes, **368***i* and **368***j*. That is, the signal applied to the bias electrodes, **368***i* and **368***j*, causes the phase offset by π/2 between two beams propagating in respective waveguides. Assuming the beam propagating in the waveguide pulled out from the 1×2 coupler **368***j* is delayed by π/2, the beam propagating in the waveguide pulled out from the 1×2 coupler **368***i* corresponds to the I-component; while, the beam in the waveguide output from the other coupler **368***j* corresponds to the Q-component. The 2×2 coupler **364***m* combines these two beams and outputs them in the output waveguides, **364***a* and **364***b*. The latter output waveguide **364***b* is terminated in the output port **37***a* in the side **32***a*, while, the former output waveguide **364***a* returns to the input portion and terminates at the monitor port **369***a* in the side **32***c*. The same situation appears in the other two waveguides pulled out from the 1×2 couplers, **368***k* and **368***m*; and the 2×2 coupler **361***n* extracts two output waveguides, **364***c* and **364***d*, the former of which is terminated in the output port **37***b* in the side **32***a*, and the latter is pulled to the input portion and terminated at the monitor port **369***b* in the side **32***d*. The monitor PDs are mounted on respective auxiliary substrates, **302***a* and **302***d*, placed adjacent to the sides, **32***c* and **32***d*.

As described above, the interconnections, **365***a*, **365***h*, receive the modulation signals in one ends thereof at the side **32***b* through the wiring substrate **33**. FIG. **13** is a perspective view showing the wiring substrate **33** that provides the sides, **33***a* and **33***b*, and eight (8) interconnections, **331***a* to **331***h*, extend from the side **33***a* to the other side **33***b*. The interconnections, **331***a* to **331***h*, are converted at the side **33***a* facing the side **32***b* of the optical modulator **32**, that is, respective ends, **331***a* to **331***h*, are electrically connected to the ends of the interconnections, **365***a*, **365***h*, on the optical modulator **32**. The other ends of the interconnections, **331***a* to **331***h*, are connected to respective drivers, **308***a* to **308***d*. As shown in FIG. **13**, respective interconnections, **331***a* to **331***h*, have length substantially equal to each other by bending them in the outer sides to compensate the electrical skews between the modulation signals.

(Receiver Module)

FIG. **14** is a plan view of an inside of the receiver module **40**. The receiver module **40** includes the receiver housing **45** and an optical receiver **40***a* installed therein. The optical receiver **40***a* provides two optical coupling systems and two optical hybrids, **43** and **44**. One of the optical coupling system is for the local beam L7 coming from the laser module **20**; while the other is for the signal beam L17 coming from the receiver optical receptacle **50***b*.

The first coupling system for the local beam L7 includes a polarizer **412**, a BS **413**, a delay element **414**, a lens system **415**, a mirror **416**, and another lens system **417**. The local beam L7 coming from the laser module **20** through the inner fiber **51***b* and entering the input port **42**, is collimated by the collimating lens **42***a*, then, arranged in the polarization thereof by the polarizer **412**. Although the laser module **20** inherently provides the local beam with the arranged polarization, transmission medium between the laser module **20** and the receiver module **40** possibly disarranges the polarization. Accordingly, the polarizer **212** rearranges the polarization of the local beam L7. The local beam L7 output from the polarizer **412** is evenly split into two beams, L21 and L22. One of the beams L21 passing the BS **413** passes the delay element **414** and enters the optical hybrid **43** as being concentrated with the lens system **415**. The other beam L22, reflected by the BS **413** toward the signal beam L17, is reflected again by the mirror **416**, advances substantially in parallel to the signal beam L17, enter the other optical hybrid **44** as being concentrated by the lens system **417**.

The second coupling system for the incoming optical signal L17 includes a collimating lens **421**, a variable optical attenuator (VOA) **422**, a BS **423***a*, a monitor PD **423***b*, a polarization beam splitter (PBS) **424**, a delay element **425**, a lens system **426**, a half-wave plate **427**, a mirror **428**, and another lens system **429**. The incoming optical signal L17, which comes from the optical receptacle **50***b* through the inner fiber **52***b* enters the input port **41**, is concentrated by the lens **41***a* in the input port **41** to pass the VOA **422**. The VOA **422** attenuates the magnitude of the incoming optical signal L17. The collimating lens **421** collimates thus attenuated incoming optical signal L17. The first BS **423***a* splits a portion of the incoming optical signal L17 toward the monitor PD **423***b*, while, a primary portion of the incoming optical signal L17 is evenly split by the second BS **424**. The monitor PD **423***b* may control the attenuation of the VOA **422**. One of the split beam L23, passing the BS **424** enters the delay element **425**, then, enters the optical hybrid **44** as being concentrated by the lens system **426**. The other beam L24 reflected by the BS **424** passes the half-wave plate **427**. The half-wave plate **427** rotates the polarization thereof by a right angle. The optical signal L24 passing the half-wave plate **427** is reflected again by the mirror **428**, then, enters the other optical hybrid **43** after being concentrated by the lens system **429**. Thus, one of the signal beams L23 entering the optical hybrid **44** and the other of the signal beams L24 entering the other optical hybrid **43** each has the polarization direction perpendicular to the other.

The coupling system thus described provides the delay element **414** for the local beam L21 and another delay element **425** for the signal beam L23. These two delay elements, **414** and **425**, may adjust phase skews between two local beams, L21 and L22, and between two signal beams, L23 and L24. The local beam L22 and the signal beam L24 enter the optical hybrids, **44** and **43**, after advancing between the BS **413** and the mirror **416**, and between the BS **424** and the mirror **428**. That is, the optical path lengths for the beams, L22 and L24, are longer than the other beams, L21 and L23, passing respective BSs, **413** and **424**, which causes a phase delay in the beams, L22 and L24. Two delay elements, **414** and **425**, causes respective phase delay substantially equal to the delays for the beams, L22 and L24; accordingly, the beams, L21 to L24, entering the optical hybrids, **41** and **43**, align the phases thereof. The delay elements, **414** and **425**, may be made of, for instance, silicon (Si).

The polarizer **412** set in the path for the local beam L7 has the function to arrange the polarization direction of the local beam L7. This is because, as already described, the laser module **20** may output the local beam L7 with an arranged polarization but the transmission medium such as inner fiber **51***b*, the output port **25***b*, the input port **42**, and so on, possibly disarranges the polarization. In addition, the tunable LD **21** in the laser module **20** may not output laser beam with the linear polarization. Although the wavelength tunable LD **21** may output a laser beam with the polarization direction primarily in parallel to the active layer of the wavelength tunable LD **21** but the laser beam inherently has a polarization component perpendicular to the active layer. Accordingly, the polarizer **412** preferably removes this polarization component perpendicular to the active layer.

The polarizer **412** may be substituted to other optical elements. For instance, a quarter-wave plate may convert the elliptical polarization into the linear polarization. Inserting the quarter-wave plate between the collimating lens **42***a* and the BS **413** instead of the polarizer **412**, or inserting the half-wave plate in addition to the quarter-wave plate between the collimating lens **42***a* and the BS **413**, the same function with the polarizer may be realized.

The optical hybrid **43** may extract information from the signal beam L24 by multiplying the signal beam L24 with the local beam L21. Specifically, the optical hybrid **43** may extract the I-component (In-phase component) and the Q-component (Quadrature-phase component) from the signal beam L24 and outputs respective components by differential signals. Similarly, the other optical hybrid **44** may extract the I-component and the Q-component from the signal beam L23 by multiplying the signal beam L23 with the local beam L22. The optical hybrid **44** may also output two differential signals.

FIGS. **15**A and **15**B schematically show examples of the optical hybrids, **43** and **44**. The optical hybrid **46** shown in FIG. **15**A provides two input waveguides, **901***a* and **901***c*, two 1×2 couplers, **902***a* and **902***c*, two 2×2 couplers, **904***a* and **904***c*, four arm waveguides, **903***a* to **903***d*, and two pairs of output waveguides, **905***a* and **905***b*, **905***c* and **905***d*, respectively. The arm waveguides, **903***a* to **903***d*, optically couple the 1×2 couplers with the 2×2 couplers. The pair of output waveguides, **905***a* and **905***b*, is coupled with the 2×2 coupler **904***a*, while, another pair of output waveguides, **905***c* and **905***d*, is coupled with the other 2×2 coupler **904***c*.

The input waveguide **901***a* provides the local beam L26, which is same with the local beam L21 or L22 in FIG. **14**, while, the other input waveguide **901***c* provides the signal beam L27, which is same with the signal beam L23 or L24 in FIG. **14**. The local beam L26 is split into two beams, L26a and L26b, by the 1×2 coupler **902***a*, while, the signal beam L27 is also split into two beams, L27a and L27b, by the other 1×2 coupler. Two beams, L26a and L26b, pass respective arm waveguides, **903***a* and **903***b*, to reach respective one input port of the 2×2 couplers, **904***a* and **904***c*. Similarly, the signal beam L27 is split into two beams, L27a and L27b, pass respective arm waveguides, **903***c* and **903***d*, and reach respective input ports of the 2×2 couplers, **904***a* and **904***c*.

The 2×2 coupler **904***a* interferes the local beam L26a with the signal beam L27a and generates two beams, L28a and L28b, whose phases are different by π (180°), to provide in respective output waveguides, **905***a* and **905***b*. Similarly, the local beam L26b is interfered with the signal beam L27b by the other 2×2 coupler **904***c*. The 2×2 coupler **904***c* generates two beams, L28c and L28d, to provide them in respective output waveguides, **905***c* and **905***d*. Putting a 90° phase shifter, which is not shown in the figures, on at least one of the arm waveguides, for instance, on the arm waveguide **903***c*, the phase of the pair of the beams, L28a and L28b, becomes different by π/2 against the other pair of the beams, L28c and L28d. Then, the pair of the beams, L28c and L28d, only includes the Q-component, while, the other pair of the beams, L28a and L28b, only contains the I-component. Thus, four output beams, L28a to L28d, contain the I-component of the phase 0, the I-component of the phase π, the Q-component of the phase π/2, and the Q-component of the phase 3π/2, respectively. The I-component and the Q-component may be extracted at the same time.

FIG. **15**B schematically shows another example of the optical hybrid. The optical hybrid **47** shown in FIG. **15**B has a feature that a 2×4 coupler is coupled in series to a 2×2 coupler. Specifically, the optical hybrid **47** includes two input waveguides, **913***c* and **913***d*, a 2×4 coupler **912**, a 2×2 coupler **914**, two arm waveguides, **913***c* and **913***d*, and two pairs of output waveguides, **915***a* and **915***b*, **915***c* and **915***d*. The two input waveguides, **911***a* and **911***b*, couples with respective input ports of the 2×4 coupler **912**. One of pairs of output ports of the is coupled with the pair of the output waveguides, **915***a* and **915***b*, while, the other of the pair of output ports of the 2×4 coupler **912** couples with the pair of input ports of the 2×2 coupler **914** through respective arm waveguides, **913***c* and **913***d*. Two output ports of the 2×2 coupler **914** are coupled with the rest of the output waveguides, **915***c* and **915***d*, respectively.

The input waveguide **911***a* receives the local beam L26, which corresponds to the aforementioned local beams, L21 and L22; while, the other input waveguide **911***b* receives the signal beam L27. Two beams, L26 and L27, enters the 2×4 coupler **912** and two pairs of the beams, L30a and L30b, L29a and L29b, are generated therein. Two beams, L30a and L30b, have a phase difference of π, similarly, other two beams L29a and L29b; also have a phase difference of π. The latter two beams, L29a and L29b, enter the 2×2 coupler **914** through respective arm waveguides, **913***c* and **913***d*. The 2×2 coupler **914** generates two beams, L30c and L30d, in the output waveguides, **915***c* and **915***d*. The generated two beams, L30c and L30d have a phase difference of π by multiplexing the beam L29a with the other beam L29b.

One of the arm waveguides, **913***c* and **913***d*, provides a phase shifter to shift a phase of a beam propagating therein. Accordingly, the output beams, L30c and L30d, provide only Q-component. On the other hand, rest of beams, L30a and L30b, which are directly output from the 2×4 coupler **912** contain only I-component. That is, four output beams, L30a to L30d, contain the I-component of the phase 0, the I-component of the phase π, the Q-component of the phase π/2, and the Q-component of the phase 3π/2. Thus, the all components contained in the signal beam L17 may be extracted at the same time.

The optical hybrid, **46** and/or **47**, which has a dimension of, for instance, 20 μm×500 μm, includes mesa shaped waveguides made of InGaAs formed on a InP substrate. The InGaAs mesas for the waveguides are buried in respective sides thereof by InP. Because InP has relatively smaller refractive index compared with that of Si, the optical hybrid, **46** and/or **47**, having such small dimensions may be available.

FIG. **16** shows a functional block diagram of the optical hybrids, **43** and **44**. FIG. **16** assumes that the optical section in the optical hybrid has an arrangement illustrated in FIG. **15**A, but the optical hybrids, **43** and **44**, may implement with the optical unit shown in FIG. **15**B. The optical hybrids, **43** and **44**, shown in FIG. **16** further provide a conversion unit **900** optically coupled with respective output waveguides, **905***a* to **905***d*, in the optical unit **46** to receive the output beams, L28a to L28d. The conversion unit **900** has four PDs, **921***a* to **921***d*, and two trans-impedance amplifiers (TIAs), **922***a* and **922***c*, that is, the conversion unit **900** provides two sets of an optical receiver each including a pair of PDs, **921***a* and **921***b*, **921***c* and **921***d*, and a TIA, **922***a* and **922***c*. The PDs, **921***a* to **921***d*, are negatively biased in the cathode thereof through respective interconnections, **923***a* to **923***d*; while the anode of the PDs, **921***a* to **921***d*, are coupled with respective inputs of the TIAs **922***a* and **922***c*.

As explained, two laser beams, L28a and L28b have a phase difference of π, and other two laser beams, L28c and

L28d, also have a phase difference of π. Accordingly, the TIAs, **922***a* and **922***b*, may receive respective two signals complementary to each other and amplify them differentially. The TIA **922***a* may output signals complementary to each other corresponding to the I-component of the signal beam, while, the TIA **922***c* may also output signal complementary to each other corresponding to the Q-component of the signal beam. These two outputs will be electrically processed by, for instance, a processor put in downstream of the TIAs, **922***a* and **922***c*.

Next, practical dimensions or sizes of the receiver module **40** will be described. FIG. **17** shows an outer appearance of the receiver module **40**. The receiver housing **45** has a rectangular shape with a length of 25~33 mm, a width of 16 mm, and a height of 6.5 mm. The receiver housing **45** provides the input ports, **41** and **42**, in the lateral side **45***a*, the RF terminals, **45***g* in the side **45***b* opposite to the former one, and the DC/LF terminals, **45***e* and **45***f*, in rest sides, **45***c* and **45***d*, connecting aforementioned two sides, **45***a* and **45***b*. The embodiment provides a total of 43 terminals including 13 RF terminals, **451***a* to **451***m*, and respective 15 DC/LF terminals, **45***e* and **45***f*. Among 13 RF terminals, 8 RF terminals, **451***b*, **451***c*, **451***e*, **451***f*, **451***h*, **451***i*, **451***k*, and **451***l*, differentially output I- and Q-components of the X polarization and I- and Q-components of the Y polarization. Rest of RF terminals, **451***a*, **451***d*, **451***g*, **451***j*, and **451***m*, are arranged between the signal terminals above described, and secured in the ground potential. Denoting differential signals as Sg and /SG, respectively, and the ground as G, the RF terminals **45***g* described above are denoted as G, Sg, /Sg, G, Sg, /Sg, G, Sg, /Sg, G, Sg, /Sg, G. The DC/RF terminals, **45***e* and **45***f*, prepared for providing DC power supplies, DC biases, the ground, and so on. These DC/RF terminals, **45***e* and **45***f*, include terminals for supplying biases to the PDs, **921***a* to **921***d*, coupled with interconnections, **923***a* to **923***d*, shown in FIG. **16**; terminals for supplying power to the TIAs, **922***a* and **922***c* and so on.

Functions available in the full duplex optical transceiver **10** will be described. As already explained, when an optical transceiver implements the digital coherent function, a local optical source for the receiver module is required in addition to the optical signal source for the transmitter module. The requirement of two optical sources sometimes prevents the optical transceiver from being formed in compact. For instance, one of standards for optical transceivers called as CFP2 is hard to realize the full duplex optical transceiver applicable to the digital coherent communication.

The full duplex optical transceiver **10** of the present embodiment implements one tunable LD **21** that provides laser light L3 to the transmitter module **30** to transmit modulated signal light in the transmitting optical fiber, and laser light L7, which is called as the local light, to the receiver module **40** to extract information from received light L17 transmitting through another optical fiber by multiplexing with the local light L7. Thus, the present optical transceiver **10** implements only one tunable LD **21**, which enables to realize a full duplex optical transceiver applicable to the digital coherent communication with a housing following the CFP2 standard.

Moreover, the laser module **20** outputs the light L13 to the transmitter module **30** extracted from the front facet **21**A of the tunable LD **21**, while, the local light L7 to the receiver module **40** extracted from the rear facet **21**B of the tunable LD **21**. This arrangement makes it possible to form the housing **11** of the optical transceiver **10** in further compact.

The inner fibers, **51***a* to **51***b*, coupling the laser module **20** with the transmitter module **30** and the receiver module **40** preferably have at least one loop. Such arrangements of the inner fibers, **51***a* to **51***b*, may release stresses possibly caused in the inner fibers, **51***a* to **51***b*, and secure the function to maintain the polarization of light transmitting therein.

Also, the inner fibers, **51***a* and **51***b*, extend from the laser module **20** in respective directions perpendicular to each other. That is, the laser module **20** has optical output ports, **25***a* and **26***a*, in respective sides perpendicular to each other. This arrangement may form the housing **11** of the optical transceiver **10** is further compact, in particular, the length of the housing **11** may be shortened.

Second Embodiment

FIG. **18** is a plan view showing an inside of an optical transceiver **10**B of the second embodiment. The optical transceiver **10**B shown in FIG. **18** has a feature distinguishable from the aforementioned optical transceiver **10** is the arrangement or the layout of the inner fibers, **51***a* and **51***b*. The inner fibers, **51***a* and **51***b*, of the present embodiment also have one loop but radii thereof are smaller than that of the aforementioned embodiment.

Specifically, the inner fiber **51***b*, pulled out from the output port **26***a* of the laser housing **24**, reaches the input port **42** of the receiver module **40** by looping between the receiver module **40** and the laser module **20** without extending in the rear portion of the housing. Similarly, the other inner fiber **51***a*, pulled out from the output port **25***a* of the laser housing **24**, forms a loop by turning almost 5/4-turns in a space surrounding by the laser module, the transmitter module **30**, and the receiver module **40**. The radii of the inner fibers, **51***a* and **51***b*, of the present embodiment are about 10 mm.

Thus, the loop for the inner fibers, **51***a* and **51***b*, in particular, the radius thereof is optional depending on the type of the optical fiber and the performance to maintain the polarization thereof. An optical fiber having a function to reduce the bending loss may be arranged with smaller loops. Adjusting excess lengths of the inner fibers as reducing the bent-stress to maintain the polarization of light propagating therein, the optical transceiver may be formed in compact.

Third Embodiment

FIG. **19** is a plan view showing an inside of a laser module **20**B according to the third embodiment of the present invention. The laser module **20**B shown in FIG. **19** has a feature distinguishable from the aforementioned laser module is that the local light for the receiver module and the source light for the transmitter module are extracted only from the front facet **21**B of the tunable LD **21**. The light output from the rear facet **21**A is used only for tuning the wavelength of the laser light.

As shown in FIG. **19**, the laser module **20**B installs the tunable LD **21** whose arrangements are same as those of the first embodiment. The laser module **20**B provides the wavelength locker **22***b* optical coupled with the face **21**A of the tunable LD **21**, and the branching system **23***b*. The wavelength locker **22***b* includes a BS **221***b*, an etalon filter **222***b*, and two PDs, **223***b* and **225***b*. The light L40 emitted from the rear facet **21**A of the tunable LD **21** is first collimated by the lens **210**, and split by the BS **221***b* into the laser beams, L41 and L42. One of the laser beam L42, reflected by the BS **221***b*, passes the etalon filter **222***b* and reaches the PD **223***b*. The other laser beam L41 reaches the other PD **225***b*. Evaluating the ratio of respective photocurrents, I1*a* and I2*a*, namely, I1*a*/I2*a*, the wavelength of the light L40 output from the tunable LD **21** may be estimated. Adjusting the temperature of the tunable LD **21** by the TEC **28**, and/or varying the current injected into the tunable LD **21** based on thus estimated wavelength, the tunable LD **21** may oscillate at the target wavelength.

The branching system **23***b* includes two BSs, **231***b* and **232***b*, and a PD **233***b*. The laser beam L6 output from the front facet **21**B of the tunable LD **21** is first collimated by the lens **211**, and then split by the BS **231***b*. One of the split beams L46 reflected by the BS **231***b* enters the inner fiber **51***a* passing through the output port **25***a*. The other of the split beam L45 passing the BS **231***b* is split again by the BS **232***b* into two beams, L47 and L48. The laser beam L47 passing the BS **232***b* enters the inner fiber **51***b* passing the output port **26***a*. The other beam L48 reflected by the BS **232***b* reaches the PD **233***b*. The output of the PD **233***b* corresponds to the magnitude of the laser beam L6.

In the present embodiment, the laser beam L46 is provided to the transmitter module **30** substituted for the laser beam L3 of the first embodiment. That is, two modules, **30** and **40**, are provided with the laser beams, L46 and L47, output from the front facet **21**B of the tunable LD **21**. Because the laser beam L40 output from the rear facet **21**A is provided only for the wavelength locker **22***b*, the split ratio of the BS **221***b* may be about 1:1, which may secure the accuracy in the calculation of the output ratio I1*a*/I2*a*.

In the foregoing detailed description, the apparatus of the present invention have been described with reference to specific exemplary embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the present invention. For instance, the tunable LD **21** may provide not only an area close to one facet but areas each close to respective facets. Also, the tunable LD **21** may provide AR coating in the face thereof. Accordingly, the present specification and figures are to be regarded as illustrative rather than restrictive.

What is claimed is:

1. An optical transceiver with a function of a full-duplex optical communication for a pair of optical fibers, comprising:

a laser module having a laser housing that encloses a wavelength tunable laser diode (LD) including a pair of facets;

a transmitter module having a transmitter housing that encloses an optical transmitter, the optical transmitter transmitting an outgoing optical signal to the one of the optical fibers by modulating a phase of a laser beam output from one of the facets of the wavelength tunable LD, and

a receiver module having a receiver housing that encloses an optical receiver, the optical receiver receiving an incoming optical signal from another of the optical fibers, the incoming optical signal being modulated in a phase thereof, the optical receiver extracting data contained in the incoming optical signal by multiplexing the incoming optical signal with another laser beam output from another of the facets of the wavelength tunable LD;

a first inner fiber and a second inner fiber, the first fiber coupling the laser module with the transmitter module, the second inner fiber coupling the laser module with the receiver module,

wherein the first inner fiber and the second inner fiber each have at least one loop between the laser module and the transmitter module, and between the laser module and the receiver module, respectively,

wherein the laser housing, the transmitter housing, and the receiver housing are separated from each other, and

wherein the first and second inner fibers are polarization maintaining fibers.

2. The optical transceiver of claim **1**,

wherein the first inner fiber extends from the laser module along a first direction, and the second inner fiber extends from the laser module along a second direction perpendicular to the first direction.

3. The optical transceiver of claim **2**,

further comprising a housing with a rectangular shape that installs the laser module, the transmitter module, the receiver module, and the first and second inner fibers therein,

wherein one of the first direction and the second direction is in parallel to a longitudinal direction of the housing, and another of the first direction and the second direction is in perpendicular to the longitudinal direction of the housing.

4. An optical transceiver with a function of a full-duplex optical communication for a pair of optical fibers, comprising:

a laser module having a laser housing that encloses a wavelength tunable laser diode (LD) including a pair of facets;

a transmitter module having a transmitter housing that encloses an optical transmitter, the optical transmitter transmitting an outgoing optical signal to the one of the optical fibers by modulating a phase of a laser beam output from one of the facets of the wavelength tunable LD; and

a receiver module having a receiver housing that encloses an optical receiver, the optical receiver receiving an incoming optical signal from another of the optical fibers, the incoming optical signal being modulated in a phase thereof, the optical receiver extracting data contained in the incoming optical signal by multiplexing the incoming optical signal with another laser beam output from another of the facets of the wavelength tunable LD;

wherein the laser housing, the transmitter housing, and the receiver housing are separated from each other,

wherein the transmitter housing has a rectangular shape with a side providing an input port and an output port, the input port receiving the laser beam provided from the laser module, the output port transmitting the outgoing optical signal to one of the optical fibers, and

wherein the transmitter housing further includes another side and rest sides, the another side being opposite to the side that provides the input port and the output port, the another side including terminals for transmitting high frequency signals, the rest sides connecting the side providing the input port and the output port to the another side, the rest sides including terminals for transmitting DC and low frequency signals.

5. The optical transceiver of claim **4**,

further comprising a transmitter optical receptacle coupled with the one of the optical fibers,

wherein the output port of the transmitter housing is connected with the transmitter optical receptacle with an inner fiber without forming any loop.

6. The optical transceiver of claim **5**,

wherein the inner fiber connecting the transmitter optical receptacle with the output port of the transmitter housing is a single mode fiber.

7. The optical transceiver of claim **4**,

further comprising a circuit board and a relay board providing electrical plug,

wherein the terminals in the another side for transmitting the high frequency signals are connected to the relay board without passing the circuit board and the terminals in the rest sides for transmitting the DC and low frequency signals are connected to the relay board through the circuit board.

8. An optical transceiver with a function of a full-duplex optical communication for a pair of optical fibers, comprising:

a laser module having a laser housing that encloses a wavelength tunable laser diode (LD) including a pair of facets;

a transmitter module having a transmitter housing that encloses an optical transmitter, the optical transmitter transmitting an outgoing optical signal to the one of the optical fibers by modulating a phase of a laser beam output from one of the facets of the wavelength tunable LD; and

a receiver module having a receiver housing that encloses an optical receiver, the optical receiver receiving an incoming optical signal from another of the optical fibers, the incoming optical signal being modulated in a phase thereof, the optical receiver extracting data contained in the incoming optical signal by multiplexing the incoming optical signal with another laser beam output from another of the facets of the wavelength tunable LD;

wherein the laser housing, the transmitter housing, and the receiver housing are separated from each other,

wherein the receiver housing has a rectangular shape with a side providing an input port and another input port, the input port receiving the another laser beam provided from the laser module, the another input port receiving the incoming optical signal from the another of the optical fiber, and

wherein the receiver housing further includes another side and rest sides, the another side being opposite to the side providing the input port and the another input port, the another side including terminals for transmitting high frequency signals, the rest sides connecting the side providing the input port and the another input port to the another side, the rest sides including terminals for transmitting DC and low frequency signals.

9. The optical receiver of claim 8,

further comprising a receiver optical receptacle coupled with the another of the optical fiber,

wherein the input port of the receiver housing is connected with the receiver optical receptacle with an inner fiber without forming any loops.

10. The optical receiver of claim 9,

wherein the inner fiber connecting the receiver optical receptacle with the input port of the receiver housing is a single mode fiber.

11. The optical transceiver of claim 8,

further comprising a circuit board and a relay board providing electrical plug,

wherein the terminals in the another side for transmitting the high frequency signals are connected to the relay board without passing the circuit board and the terminals in the rest sides for transmitting the DC and low frequency signals are connected to the relay board through the circuit board.

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